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Calibration of Thin-Foil Manganin Gages for MFG/DQA

Gregg R. Peevy, Wayne G. Rivera, Robert A. Benham, and Benjamin D. Duggins

Prepared by
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Calibration of Thin-Foil Manganin Gages for MFG/DQA

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Abstract

A Manganin (Mn) thin-foil gage calibration series consisting of seventeen light gas gun experiments was conducted between July 25th and August 9th, 2000. To date two lots of production quality Mn gages, manufactured by the Measurements Group Inc., Micro-Measurements division, for Manganin Foil Gage (MFG) pressure transducers have been received and used. Currently, an additional third lot of 1500 Mn gages have been purchased to support Timer production acceptance activities using the MFG Pressure Transducer, 706140. These gages were manufactured from the same sheet of Mn alloy foil material as the first two lots of Mn gages. In addition to the 1500 MFG gages purchased, an additional 1000 Mn gages were purchased to support explosive Driver production acceptance activities using the Driver Qualification Assembly (DQA) Transducer.

The current work described in this report is as follows:

1. Preliminary tests done to verify the light gas gun set-up and to validate that these tests produced the same results as the gas gun tests done on previous calibration test series of Mn gages.
2. Recalibration series done to establish an agreement of the performance of a new lot of Mn gages (same Mn alloy material from previous lots) with the calibrated gages used to generate the original calibration curve in non-homogeneous ALOX/Z material. These Mn gages are to be used in the 706140 MFG Pressure Transducer.
3. Calibration series aimed at extending the previous ALOX/Z calibration curve to include higher-pressure data (150 kbar), using the new lot of MFG Mn gages.

4. New calibration series conducted in homogeneous PMMA, aluminum, and copper material to establish performance of a new batch (new Mn alloy material) of Mn gages. These gages are to be used in the production of 709995 Driver Qualification Assembly (DQA) Transducer.

These Mn gages measure stress as a function of *change in gage resistance/gage resistance* ($\Delta R/R$). The light gas-gun located at Sandia National Laboratories, New Mexico Location, Explosive Components Facility (ECF), Building 905, was used to drive an impactor into the target containing two or four Mn gages in a centered arrangement. Tilt and velocity of the impactor were measured along with the gage outputs, as well as other diagnostic techniques. The thin Mn gage and high-speed instrumentation resulted in high output resolution measurements, and a successful test series. The areas of investigation that will be presented include, experimental setup, comparison with existing calibration curves, and discussions of the extended calibration data.

Acknowledgments

The authors would like to thank all of the individuals who participated in the activities of this report and to Linda Ainsworth and Dolores Maes for preparing this report for publication. Personnel that participated in the activities are listed below.

Task	**Personnel Responsible for Task**
Manufacture of projectiles and targets	H. Anderson (Ktech), 1610, P. Brophy, 2553
Assured that Paperwork for tests, targets, and procedures were in place.	P. Brophy, 2553 T. Garcia, 2553
Conducted the data recording	D. Wackerbarth, 2554, B. Duggins (contractor)
Conducted the gas gun tests	D. Sanchez, 2554, J. Liwski (Ktech), 1610
Obtained manganin thin-foil gages	R. LeBlanc, 2553
VISAR data reduction	W. Brigham and T. Broyles, 2554
Test Design and Data Reduction	R. Benham, B. Duggins, W. Rivera, G. Peevy

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Nomenclature

ALOX/Z	42% by volume alumina in EPON 828 epoxy
	Epoxy Resin (Epon 828) 100 parts by weight (PBW), Filler (Aluminum Oxide Al_2O_3) 300 PBW, and Curing Agent (“Z”)/hardener 20 PBW
PMMA	Polymethyl Methacrylate (type POLY II UVT made by Polycast Technology Corporation)
kbar	Kilobar (1,000 bars or 0.1 gigapascals - GPa)
MFG	Sandia National Laboratories Drawing Number 706140 MFG (Manganin Foil Gage) Pressure Transducer
DQA	Sandia National Laboratories Drawing Number 709995 Driver Qualification Assembly Transducer
Mn	Manganin
ECF	Explosives Components Facility, Building 905, Sandia National Laboratories New Mexico Location
VISAR	Velocity Interferometer System for Any Reflector

1.0 Introduction

Manganin (Mn) alloy has been used widely as a stress gage for planar shock wave experiments. Embedded gages of the wire design have been studied by Lee (Reference 1) and have been used in numerous physics and engineering applications. Because of the physical size of the Mn wire, 0.003 inch diameter, the sensing element responds relatively slowly to an input shock and the gage output is dependent on the material in which the gage is mounted. The thin foil Mn gage construction, as reported by Rosenberg (Reference 2), and used in the tests of this report, is much thinner, 0.0002 inch, and provides a better temporal representation of the shock in materials. This design, with gage backing in place, is reported to be insensitive to the target material. Rosenberg reported that the calibration curve for the thin foil Mn gage showed distinct elasto-plastic behavior with a linear portion from 0 to 15 kbar. The slope of the elastic part of the calibration was ~5 kbar/(Ω/Ω), where Ω/Ω is in percent. Stresses above 15 kbar were represented by a fourth-order polynomial fit. The target and impactor materials used in the Rosenberg work were PMMA (Polymethyl Methacrylate), copper, magnesium and aluminum, all homogeneous in nature. This curve is documented further in Section 2.0.

A shock response calibration curve for the commercial foil gages that have the customary Kapton® backing removed and the gages imbedded in ALOX/Z was developed by Benham et al in 1995 (Reference 3, Appendix D) and extended in 1998 (Reference 3, Appendix D).

The Mn gages used in the experiments for the Manganin Foil Gage (MFG) pressure transducer (Reference 3) were fabricated from the same sheet of Mn foil material used when generating the existing curve and manufactured by the same supplier, Micro-Measurements (Model No. VM-SS-110FB-048, Part No. C-971125-B; Sandia National Laboratories drawing number 709226-000). The Mn foil used to make the gages for the experiments for the DQA were from a new Mn alloy material and manufactured, again, by Micro-Measurements (Model No. VM-SS-110FB-048/SP-11, Part No. C-990825-A; Sandia National Laboratories drawing number 710538-000). Two or four gages were installed in each target to obtain redundant gage outputs from the same test input. Figure 1 shows two Mn gages mounted and stripped on a 2 inch diameter target plate (see complete projectile and target assembly in Figure 5).

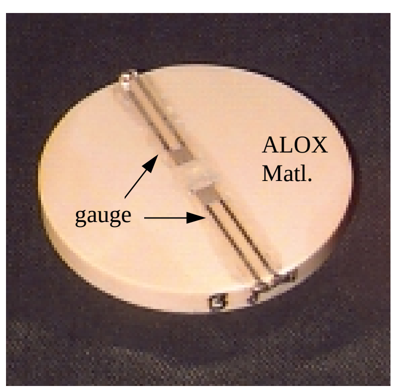


Figure 1. Gages mounted on ALOX/Z target

Usage of the Mn gage in production and development activities has gone far beyond our initial expectations. To date two lots of production quality Mn gages for MFG pressure transducers have been received and used. Currently, an additional third lot of 1500 Mn gages were purchased to support Explosive Timer production acceptance activities using the MFG Pressure Transducer, 706140. As stated above, these gages were manufactured from the same sheet of Mn alloy foil material as the first two lots of Mn gages. In addition to the 1500 MFG gages purchased, an additional 1000 Mn gages were purchased to support explosive Driver production acceptance activities using the Driver Qualification Assembly (DQA) Transducer or similar device (Reference 3, Appendix M). Previous Mn gage calibration and special test gas gun series are described below in Section 2.0.

The current work described in this report is as follows:

1. Preliminary tests done to verify the light gas gun set-up and to validate that these tests produced the same results as the gas gun tests done on previous calibration test series of Mn gages.

2. Recalibration series done to establish an agreement of the performance of a new lot of Mn gages (same Mn alloy material from previous lots) with the calibrated gages used to generate the original calibration curve in non-homogeneous ALOX/Z material (42% by volume alumina in EPON 828 epoxy, Reference 4). These Mn gages are to be used in the 706140 Manganin Foil Gage (MFG) Pressure Transducer.

3. Calibration series aimed at extending the previous ALOX/Z calibration curve to include higher-pressure data (150 kbar), using the new lot of MFG Mn gages.

4. New calibration series conducted in homogeneous PMMA, aluminum, and copper material to establish performance of a new batch (new Mn alloy material) of Mn gages. These gages are to be used in the production of 709995 Driver Qualification Assembly (DQA) Transducer, or similar device.

Table 1 describes the calibration and special test activities plan to be performed. A Hugoniot shock calculation computer code, using established hugoniot material parameters (Reference 5), was used to predict the pressures measured by the Mn gages in the gas gun series that have not been done before.

Table 1. Manganin Gage Calibration Test Matrix Plan

Test Description and Serial Number	# Tests	Impactor Material	Buffer Mat'l	Target Mat'l	Projectile Impact Velocity (mm/us)	Particle Velocity Up (mm/us)	Target Pressure (kbar)	Notes
Set-up **MFG4-SU1** **MFG4-SU2**	2	PMMA (Polycast)	PMMA (Polycast)	PMMA (Polycast)	1.492	0.746	33.0	A, 1
Cal for MFG **MFG4-1** **MFG4-2** **MFG4-3 (spare)***	2	ALOX/Z	ALOX/Z	ALOX/Z	0.778	0.389	33.0	A, 1, 2
Cal for MFG **MFG4-4** **MFG4-5** **MFG4-6 (spare)****	2	ALOX/Z	ALOX/Z	ALOX/Z	1.267	0.633	61.0	A, 1, 2
Cal for DQA **DQA-1** **DQA-2** **DQA-3 (spare) ****	2	PMMA (Polycast)	PMMA (Polycast)	PMMA (Polycast)	1.492	0.746	33.0	A, 1
Cal for DQA **DQA-4** **DQA-5** **DQA-6 (spare) ****	2	Aluminum 6061-T651	Aluminum 6061-T651	Aluminum 6061-T651	1.150	0.575	95.1	B, 1
Cal for DQA **Check perf.** **DQA-7** **DQA-8**	2	Aluminum 6061-T651	Aluminum 6061-T651	Sapphire	1.190	0.330	151.3	B, 3
Cal for DQA **DQA-9** **DQA-10**	2	Copper	Copper	Copper	0.763	0.382	152.6	B, 1
Ext cal for MFG **MFG4-7** **MFG4-8** **MFG4-9 (spare)****	2	Copper	ALOX/Z	ALOX/Z	1.565	1.196	146.8	A, 1

General notes:

2 gages on target, positioned 180 degrees apart

Gage mounted between buffer and target

* MFG4-3 was built as a spare target and used at the 61.0 kbar range

** Spare units not assembled or tested

Specific notes:

(A) Mn gage stripped

(B) Mn gage not stripped and insulated from metal surface with 1 mil thick kapton

(1) Match particle velocity as closely as possible

(2) Include two previously calibrated gages to verify new ALOX material properties - 4 gages total

(3) VISAR measurement to verify technique
No Mn gages on DQA-7 (VISAR only)
2 Mn gages on DQA-8 plus VISAR

2.0 Previous Calibration Curves

Prior to the completion of this current calibration series, there were three commonly used calibration curves in use for Manganin Gages at Sandia. These include the Rosenberg Curve (Reference 2), the NBD95 Curve (Reference 3, Appendix D), and the MAC97 Curve (Reference 3, Appendix D). These calibration curves covered pressure ranges between 0 and 100 kbar for both homogeneous and ALOX/Z (non-homogeneous) materials, and are given in Figure 2.

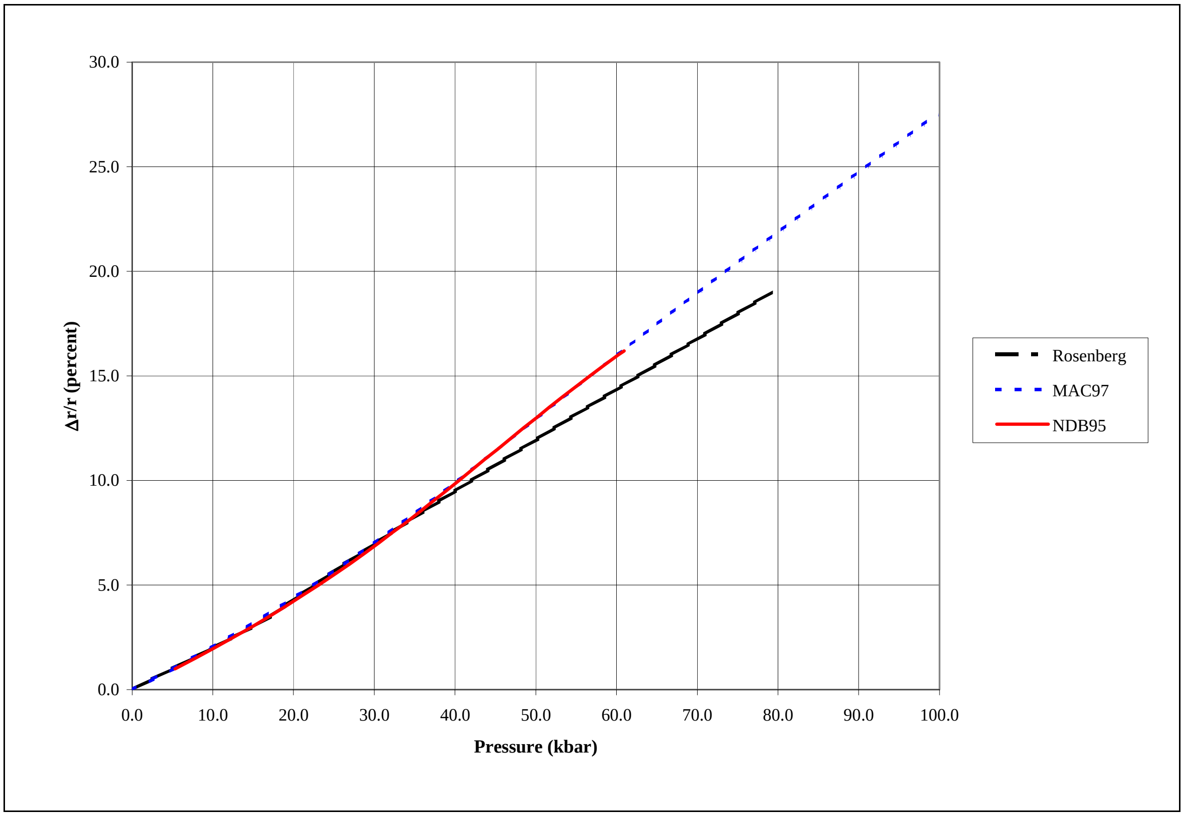


Figure 2. Previous Manganin Gage Calibration Curves

2.1 Rosenberg Homogeneous Calibration Curve

For pressures between 0 and 15 kbar:

$$P = 500\ (\Delta r/r)$$

For Pressures between 15 kbar and 80 kbar:

$$P = 5.72 + 295.9\ (\Delta r/r) + 952.0\ (\Delta r/r)^2 - 3{,}127.4\ (\Delta r/r)^3 + 3{,}317.7\ (\Delta r/r)^4$$

Where:

P is pressure in kbar

$\Delta r/r$ is the change in resistance of the Mn gage divided by the initial gage resistance.

Also, Δr/r is calculated from digitized data by the following parameters

$$e = e_{out} \times 2$$

$$a = ex \times RSER$$

$$c = RSER + R_T$$

$$\Delta r = a \times \left(\frac{c}{a + c \times (-e)} - \frac{c}{a} \right)$$

$$\frac{\Delta r}{r} = \frac{\Delta r}{RG} \times 100$$

Where,

e_{out} = MFG voltage out (V) at time of interest

ex = excitation voltage 100V

RSER = value of series completion resistor = 86.6 Ω

R_T = total resistance = RG + resistance of MFG cable + resistance of tester cable (Ω)

RG = gage resistance (48 Ω)

Δr = change in gage resistance due to the pressure/strain at the time of interest

2.2 NBD95 and MAC97 Calibration Curves

Manganin gage calibration series were conducted in 1995 (Reference 3, Appendix D) and 1997 (Reference 3, Appendix D) using the Light Gas Gun at Sandia National Laboratories Explosive Components Facility (ECF) pictured in Figure 3. These tests were conducted to calibrate the Manganin gages in a non-homogeneous ALOX/Z material. Because the MAC97 Curve extended the NBD95 curve, the latter was no longer used at Sandia, and specific formulas are not given below, but can be found in Reference 3, Appendix D.

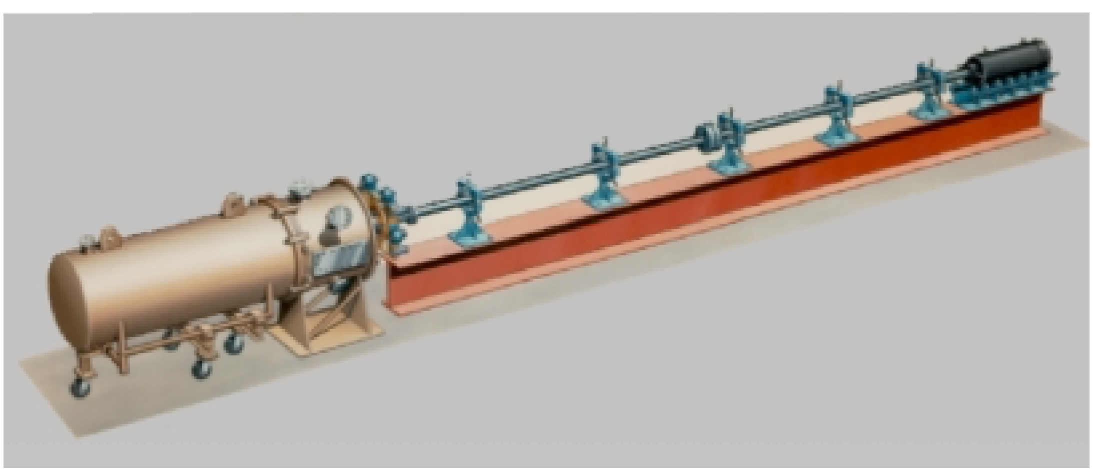


Figure 3. SNL ECF Light Gas Gun (Not to Scale)

MAC97 Calibration Curve for pressures between 1 kbar and 100 kbar:

$$P = 5.23994500\ (\Delta r/r) - 0.17979031\ (\Delta r/r)^2 + .0069336032\ (\Delta r/r)^3 - .00009205846\ (\Delta r/r)^4$$

Where:
P is pressure in kbar
$\Delta r/r$ is the change in resistance of the Mn gage divided by the initial gage resistance, quantity times 100 (to put in percent)

Again, pressure is calculated from digitized data by the following parameters

$$e = e_{out} \times 2$$
$$a = ex \times RSER$$
$$c = RSER + R_T$$
$$\Delta r = a \times \left(\frac{c}{a + c \times (-e)} - \frac{c}{a} \right)$$
$$\frac{\Delta r}{r} = \frac{\Delta r}{RG} \times 100$$

Where,
e_{out} = MFG voltage out (V) at time of interest
ex = excitation voltage 100V
RSER = value of series completion resistor = 86.6 Ω
R_T = total resistance = RG + resistance of MFG cable + resistance of tester cable (Ω)
RG = gage resistance (48 Ω)
Δr = change in gage resistance due to the pressure/strain at the time of interest

3.0 Experimental Technique

The same light gas gun used for the previous Sandia calibration tests, located at the SNL Explosives Components Facility, was used for this current calibration test series. The gun has the capability of propelling a projectile at velocities ranging from approximately 25 meters/second up to 1.75 kilometers/second. The gun was used to drive a projectile to impact targets at specified velocities in order to introduce a well-controlled and characterized shock impulse into the selected targets. This gun has an inner bore diameter of 2.5 in. and a length of 60 ft. Helium was used to pressurize the breech due to the need for higher projectile velocity shots (greater than 600 m/s). A block schematic of the gun system is shown in Figure 4.

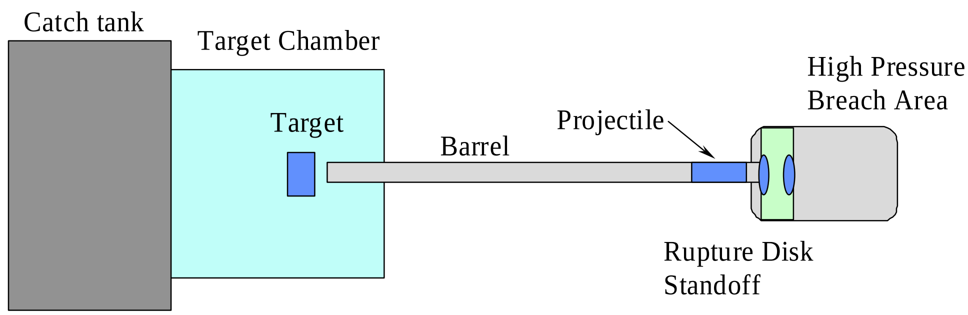


Figure 4. Block diagram of light gas gun.

The firing pressure of the breach was determined from a gas gun software program, which estimates the pressure for the given projectile weight and selected projectile velocity. The projectile was loaded into the barrel, and a dual diaphragm rupture disk assembly was inserted into the breach. The target/buffer assembly, containing the Mn gages and tilt pins, as well as the velocity pin block, were mounted in the target chamber and all cabling and instrumentation hook-ups were completed. Upon completion of the target installation, the target chamber was closed, then the chamber and barrel were evacuated. Once evacuated, pressurizing of the breech was begun. When the system was pressurized to the specified level the projectile was fired.

The impact velocity of the projectile was measured using five coaxial pins, mounted to the velocity pin block, which were shorted by a metallic ring around the projectile on impact. The pins were separated by 10 mm in the axial direction, where the last pin was located 62 mm in front of the target assembly face. The accuracy of the impact velocity is typically +/- 0.5% (see Figure 5)

The impactor tilt was measured by four sets of tilt pins placed on the target cup and shorted by the metallic ring on the projectile at impact. The tilt pins were equally positioned around the target axis. The impactor tilt was calculated from the output of the four signals (see Figure 5).

Figure 5 is a schematic of the projectile and target assemblies. The impactor material for the preliminary set up and validation tests was POLY II UVT type PMMA made by the Polycast Technology Corporation. Previous work by J. D. Matthews and L. J. Wierick was done to show that the POLY II UVT type PMMA, as manufactured by Polycast, exhibited nearly identical shock behavior, for pressures less than 50 kbar, as the previously used Rohm and Haas manufactured PMMA (Reference 6). Certifications were obtained for all materials used in the test series. Note that the ALOX/Z material used in this test series was a different batch than that used in the previous Mn gage calibration work. ALOX/Z slugs were fabricated at Sandia National Laboratories Advanced Manufacturing Processes Laboratory (AMPL) per Specification SS707932-001 Manganin Foil Gage (MFG) Pressure Transducer (Reference 4). To ensure that the ALOX/Z material properties of this new batch were the same as documented in the previous calibration work, two Mn gages from a previously calibrated lot were assembled in the target assemblies of four of the current tests.

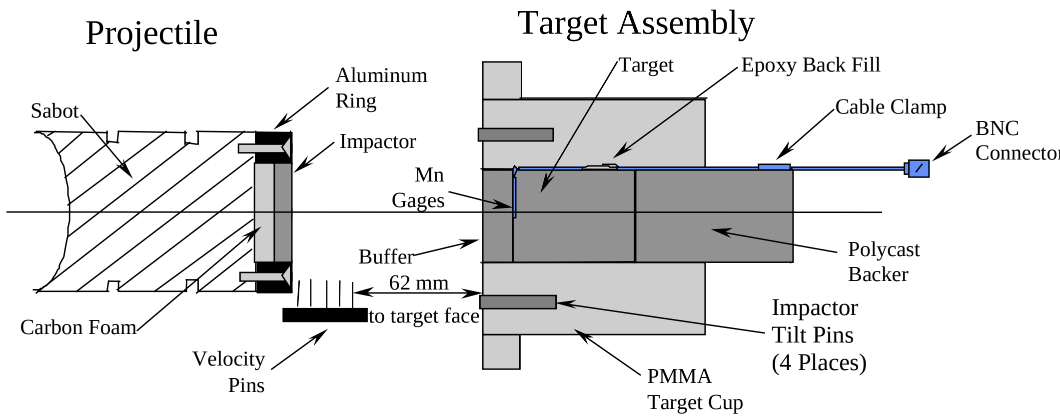


Figure 5. Projectile and target assemblies.

The projectile impactor was 0.1 inch thick by 2.0 inch diameter and was backed by a 0.2 inch thick disk of carbon foam, which had a nominal density of 0.2 g/cm^3. This backing material reflects a very small percentage (~4%) of the shock wave reaching it from the impactor. The projectile (Sabot) to carry the impactor was made of nylon filled with syntactic foam. Using the same material for the impactor and target, as was the case for thirteen of the seventeen tests, produced a symmetric impact with the resultant particle velocity in the target material equal to one-half of the projectile velocity. For the four higher stress tests, the impactor and target material were different. The stress level in the impacted material in both cases was determined from the known Hugoniot curves and the measured impact velocity determined by the impedance-match technique. Material properties for Hugoniot shock calculations are given in Table 2 (References 5, 6, 7, and 8). Material properties for Sapphire, Aluminum, and Copper were taken from the CTH Hydrocode library (Reference 5 and 8). Pressure, in giga-pascals (1 Gpa = 10 kbar) can be calculated from values in Table 2 and the formula:

$$P = \rho \cdot u_p \cdot \left(c_0 + s \cdot u_p\right)$$

Table 2. Material Hugoniot Parameters

Material	**Density ρ (g/cc)**	**c_o (mm/ms)**	**s**
PMMA Polycast II UVT (Reference 6)	1.190	2.490	1.690
ALOX (Reference 7)	2.375	2.807	1.972
Sapphire (Reference 8)	3.985	11.190	1.000
Aluminum (Reference 5)	2.703	5.240	1.400
Copper (Reference 5)	8.930	3.940	1.489

The Mn gages were sandwiched between two pieces of material, as seen in Figure 6. The first piece, the buffer, was nominally 0.1 or 0.2 inch thick and the second, the target, was greater than 0.5" thick. The Polycast backer was used to support the instrumentation cable connections shown in Figure 5 and Figure 6.

Figure 6. Manganin gage/PMMA target assembly.

The Mn gages are etched foil with 48 Ω nominal resistance. The foil was 0.0002 inch thick and the Kapton® backing was removed after the gages were glued to the respective target where metallic shorting of the gage was not anticipated. The total thickness of the gage installation between the buffer and the target was nominally twice the gage thickness. The Mn gage has two thin ribbon leads for attachment to the instrumentation cable which were coated with a thin layer of copper (~ 0.0002 inch thick) to reduce output caused by a resistance change of the leads during impact.

For target assemblies that were comprised of aluminum or copper, the Mn gages were not stripped because the metallic surfaces would short the gage. In these cases, the Kapton® backing remained in place, and a second layer of Kapton® was glued to the exposed face of the gage. The total thickness of the gage installation between the buffer and target was nominally 0.001 inches. This design proved to be extremely reliable in obtaining good data. The extra thickness of Kapton® slightly effected the rise time of the shock pressure but did not effect the level of the flat top portion of the pulse.

To provide an independent verification of particle velocity, and thus pressure achieved, where the impactor/buffer and target were different materials, a VISAR (Velocity Interferometer System for Any Reflector) system was used. This Push-Pull, Double-Delay-Leg or Dual VISAR, used an argon ion 514.5 nm wavelength laser (Lexel 95) (References 9, 10, and 11). Particle velocity in the target material was measured by having a piece of reflective foil between the target and the buffer (the location of the Mn gage). The target material was a transparent piece of sapphire, allowing for high pressure development at impact and for the laser light to penetrate the material to impinge on the embedded reflector.

3.1 Procedures

This section is to document Explosives Components Department 2553 management and Quality Engineering & Business Practices Department 14408 concurrence with the test plan for calibration of additional Mn gages and special tests described in Section 1.0 and Appendix A. Department 2553 management has stated that “The procedures for performing these calibration tests will be used in their current state. Though there have been extensive changes proposed for these procedures, the changes are administrative in nature and will not affect the results obtained from the tests" (see Appendix A, e-mail from G. Scharrer, dated 6/12/00). Table 1 and Table 2, of section 2, present the test plan and material properties used for Hugoniot code shock calculations. Tests conducted will be technically identical to the previous test series performed in July and August 1997 with the exception that some tests will be performed at higher pressures (120 – 150 kbar) to extend the gage calibration curves for ALOX/Z (Manganin Thin-Foil Gage Pressure Transducer – MFG) and PMMA (Driver Qualification Assembly – DQA). Test setup, procedures, and calculation methods are the same from the previous test. Note that the procedure for producing and measuring test specimen flatness has been upgraded.

The following documents with red lined corrections per memo from Salas to Peevy dated 8/14/97 (Appendix A), were scanned into the Sandia National Laboratories document management system, Image Management System (IMS), by T. Garcia for document control.

1. "Manganin Gage Calibration Testing with the MC3359A/B Tester" Doc. No. OI-MC3359A/B-005 Issue A dated 3/22/95
2. "Installation Procedures and Data Recording for the Time Interval Meter Used for Calibrating the Thin-Foil Manganin Gage" Doc. No. OP-GUAT922.1 Issue A dated 3/30/95
3. "Assembly Procedures for Calibration of the Thin-Foil Manganin Gage (MFG-K) Pressure Transducer (U)" Doc. No. OP-HAT922.1 Issue A dated 3/31/95
4. "Procedures for Assembly of Velocity Pin Block" Doc. No. OP-VPAT922.1 Issue A dated 3/30/95
5. "Calibrating the Micro-Measurements Thin-Foil Manganin Gages" Quality Assurance Program Doc. No. 922-5001-311 Issue B dated 4/12/95

The Light-Gas Gun used to perform the calibration test series was operated using the current Building 905 Explosives Components Facility (ECF) operating procedures, Light-Gas Gun Operating Procedure, OP-905-0021, Issue C, dtd. 6/30/97.

The following memos were included in a data package submitted to IMS for archival. This was to document the test plan and the administrative changes.

1. Memo, W. Rivera and G. Peevy to Distribution, dtd. 6/27/00, subject: Plan for Calibration of Additional Thin-Foil Manganin Gages and Special Tests Update
2. Memo, W. Rivera and G. Peevy to Distribution, dtd. 3/20/00, subject: Plan for Calibration of Additional Thin-Foil Manganin Gages and Special Tests
3. Memo, J. Salas to G. Peevy, dtd. 8/14/97, subject: Corrections to Procedures for Gage Calibration Series
4. Memo, J. Salas to G. Peevy, dtd. 7/31/97, subject: Procedures for MFG Calibration Series

A gage calibration test readiness review meeting was held with Management and Quality personnel on June 27, 2000. Management and Quality concurrence to proceed with the test series as defined above was given and recorded in memo from W. Rivera and G. Peevy, dated 6/27/00, Appendix A.

3.2 Test Sequence

A summary of the desired calibration test conditions is given in Table 1 in Section 1.0. A comprehensive test matrix, including test order, test configuration and desired conditions, is given in Table 1 of Appendix B.

This test series was set up in four parts. The ***preliminary tests*** (test identification MFG4-SU1 and -SU2) were done to verify the light gas gun set-up and to validate that these tests produced the same results as the previous gas gun tests done on previous calibration of gages in 1995, 1997, and 1998 (Reference 3, Appendix D). The purpose of these tests was to validate the experimental process.

The second set of tests, the ***recalibration tests*** (test identification MFG4-1, -2, -3, -4, and -5), were conducted to establish an agreement of the performance of the new lot of Mn gages (same Mn alloy foil material from previous lots) with the calibrated gages used to generate the original calibration curve in ALOX/Z. These gages, designated “MFG”, are to be used in the 706140 MFG Pressure Transducer. These tests utilized the previously calibrated Mn gages, in addition to new Mn gages, to ensure the ALOX/Z material properties and gage performance was comparable to previous test series.

The third set of tests, the ***extension series*** (test identification MFG4-7 and -8), were aimed at extending the previous ALOX/Z data set to include a higher pressure (150 kbar). Thus allowing the extension of the calibration curve for these gages.

The fourth set of tests, ***DQA calibration series*** (test identification DQA-1, -2, -4, -5, -7, -8, -9, and -10), the new calibration tests, were conducted to establish performance of a new lot (new Mn alloy material) of Mn gages. These gages are to be used in the production of DQAs. DQA-7 utilized VISAR only, and DQA-8 used both VISAR and new Mn gages.

3.3 Discussion and Test Results

Discussion and test results of the four parts of this calibration test series are given below. Appendix B of this report, gives the summary results of all the previous calibration tests.

3.3.1 Preliminary tests (MFG4-SU1 and -SU2)

The preliminary tests were conducted to provide data for comparison with the original calibration data to assess overall experiment accuracy. These preliminary tests (two each) were conducted with the gages sandwiched between PMMA material and designed to produce 33 kbar pressure loading in the material in a symmetrical impact (Reference 12). The Mn gages were stripped of the backing and were installed in the same manner as for the ALOX/Z experiments. The results of the PMMA (POLY II UVT) tests for this and the 1998, 1997, and 1995 tests are shown in Table 3 and Appendix B. Typical gage output for the gas gun tests is given in Figure 7.

Table 3. MFG4-SU1 and –SU2 Test Results

Test ID	Calculated Pressure (kbar) *	Target Material	Gage	Gage Readings (kbar) **	Dev. (%)
MFG4-SU1	32.04	PMMA	1	31.57	-1.5
			2	31.79	-0.8
MFG4-SU2	33.37	PMMA	1	32.49	-2.6
			2	32.42	-2.8

Notes: * Pressure calculated from projectile velocity and Hugoniot Data.
** Pressure readings using MAC97 calibration curve.

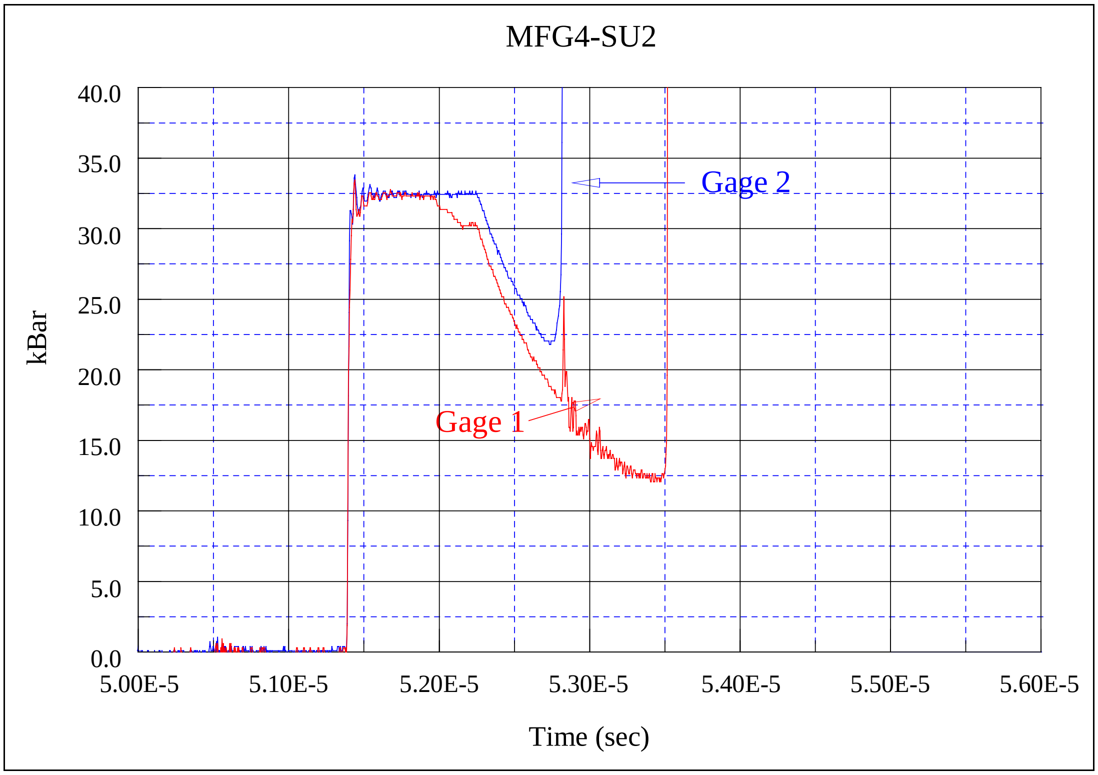


Figure 7. Typical gage output (MFG4-SU2)

The following observations verified that these gas gun tests (MFG4-SU1 and -SU2) produced the same results as the previous gas gun tests:

1) The gas gun produced the desired velocities that gave ~33 kbar, thus demonstrating the quality of the Gas Gun operation at the ECF.

2) The signals from the new MFG Mn gages, tests MFG-SU1 and -SU2 (Table 3), produced pressures that were within – 2.8 % to - 0.8 % of the delivered values when the MAC97 calibration curve for 1 kbar to 100 kbar was used.

These observations verify that the new MFG Mn gages, C-971125-B, give the same output in PMMA materials, within experimental tolerances, at this test level.

The MAC97 calibration curve is defined in Section 2.

3.3.2 Recalibration tests (MFG4-1, -2, -3, -4, and -5)

Both new MFG and previously calibrated (PC) gages were used for the recalibration series (MFG4-1, -2, -3, -4, and -5). Two tests were conducted at a pressure level of 33 kbar and three tests were conducted at 61 kbar, duplicating the pressure range of the previous calibration series. Four gages were used in each test (20 gages total). Tests MFG4-1, -2, -4, and –5 used both new and previously calibrated MFG gages. Test MFG4-3 used four new Mn gages to observe any possible inconsistencies in the pulse power supplies used to power the gages (no inconsistencies were observed). The results of the ALOX/Z tests for this and the 1998, 1997, and 1995 tests are given in Appendix B. Data for this test series is given in Table 4.

The following observations come from these data:

1) The set of data from each Mn gage, at the two levels, are very close together (within 3.7%), showing good gage repeatability for both previously calibrated and new gages, as pictured in Figure 8.

2) The new MFG Mn pressure gages give good agreement (- 2.2 to + 0.8%) with the pressure calculation from the Hugoniot using the particle velocity from the impact produced at the 33 kbar range in the new ALOX/Z (compared to 1995 data). MAC97 calibration curve from Appendix D of Reference 3 is given in Section 2.2 for convenience.

3) The new MFG Mn pressure gages also give good agreement (- 2.4 to 0.6 %) with the pressure calculation from the Hugoniot using the particle velocity from the impact produced at the 61 kbar range in the new ALOX/Z (compared to 1995 data). It is believed that the one – 6.9 % data point is an anomaly. Test MFG4-3 was performed to verify that the – 6.9 % data point was anomalous. These four new Mn gages on test MFG4-3 all agreed very closely (– 2.4 to – 1.9 %).

4) The previously calibrated MFG Mn pressure gages for the new batch of ALOX/Z give good agreement (- 3.7 to + 3.4 % at 33 kbar and – 2.9 to 3.2 % at 61 kbar) with the original batch of ALOX/Z (- 1.8 to + 0.98 % at 33 kbar and – 2.7 to 4.1 at 61 kbar), indicating that the material properties of the two batches of ALOX/Z are nearly the same.

Table 4. Recalibration Tests (MFG4-1, -2, -3, -4, and –5)

Test ID	Calculated Pressure (kbar) *	Target Material	Gage	Gage Readings (kbar) **	Dev. (%)
MFG4-1	33.91	ALOX/Z	1	33.45	-1.4
			2	33.16	-2.2
			3 PC	32.99	-2.7
			4 PC	35.05	3.4
MFG4-2	32.52	ALOX/Z	1	32.78	0.8
			2	32.71	0.6
			3 PC	31.32	-3.7
			4 PC	32.85	1.0
MFG4-3	63.98	ALOX/Z	1	62.47	-2.4
			2	62.66	-2.1
			3	62.76	-1.9
			4	62.57	-2.2
MFG4-4	62.05	ALOX/Z	1***	57.74	-6.9
			2	62.40	0.6
			3 PC	64.06	3.2
			4 PC	63.30	2.0
MFG4-5	63.20	ALOX/Z	1	62.70	-0.8
			2	62.66	-0.8
			3 PC	63.30	0.2
			4 PC	61.37	-2.9

Notes: * Pressure calculated from projectile velocity and Hugoniot Data.
** Pressure readings using MAC97 calibration curve.
*** Anomalous data.
PC From previously calibrated gage lot.

Note: Higher pressure levels in 1997 and 1998 data were attributed to possible hardening effects in the ALOX/Z material when it ages, see Appendix D of Reference 3.

These tests indicate that the new lot of Mfg Mn gages C-971125-B are like previous lots and that the MAC97 calibration curve applies to all of these gages.

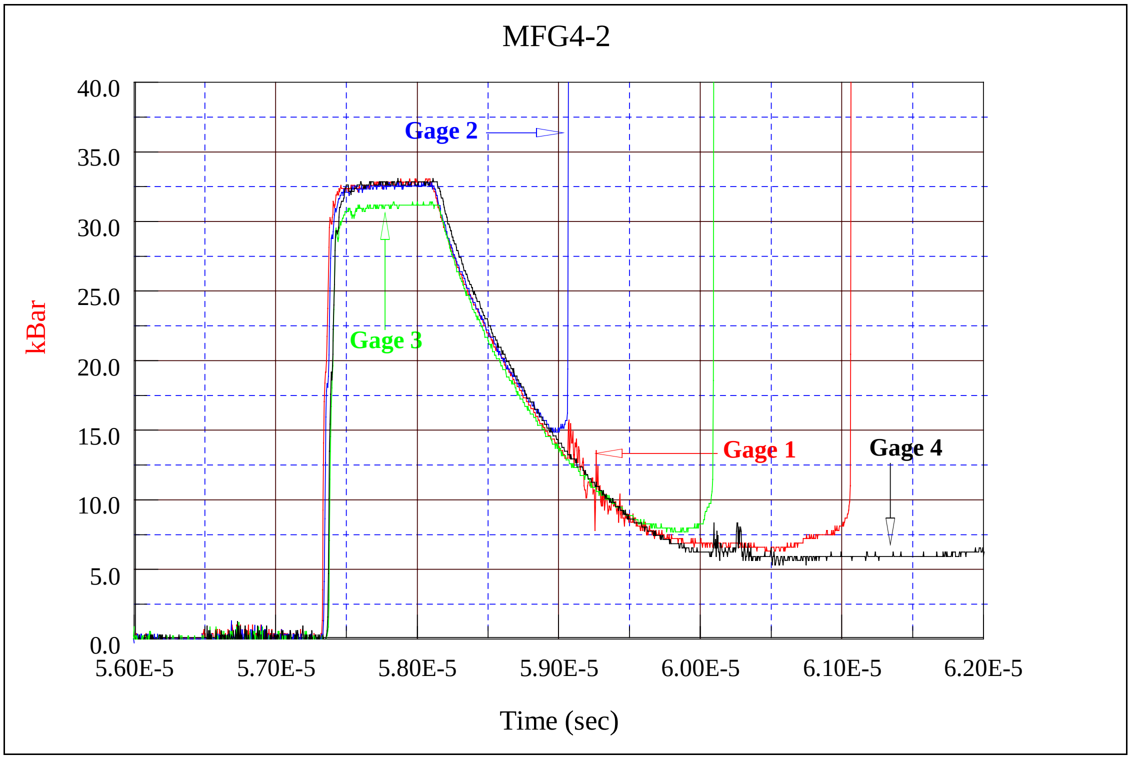


Figure 8. Gage output from new and previously calibrated gages (MFG4-2).

3.3.3 Extension series (MFG4-7 and -8)

The third set of tests, the *extension series* (test identification MFG4-7 and -8) were aimed at extending the previous ALOX/Z data set to include higher pressure (150 kbar) data to extend the calibration curve for the MFG Mn gages. The test results are shown in Table 5 and Figure 9.

Table 5. Extension Series (MFG4-7 and –8)

Test ID	Calculated Pressure (kbar) *	Target Material	Gage	Gage Readings (kbar) **	Dev. (%)
MFG4-7	146.8	ALOX/Z	1	145.9	-0.6
			2	142.6	-2.8
MFG4-8	143.0	ALOX/Z	1	147.6	3.2
			2***	121.0	-15.4

Notes: * Pressure calculated from projectile velocity and Hugoniot Data.
** Pressure readings using MAC00 calibration curve.
*** Anomalous data (ALOX may have become conductive).

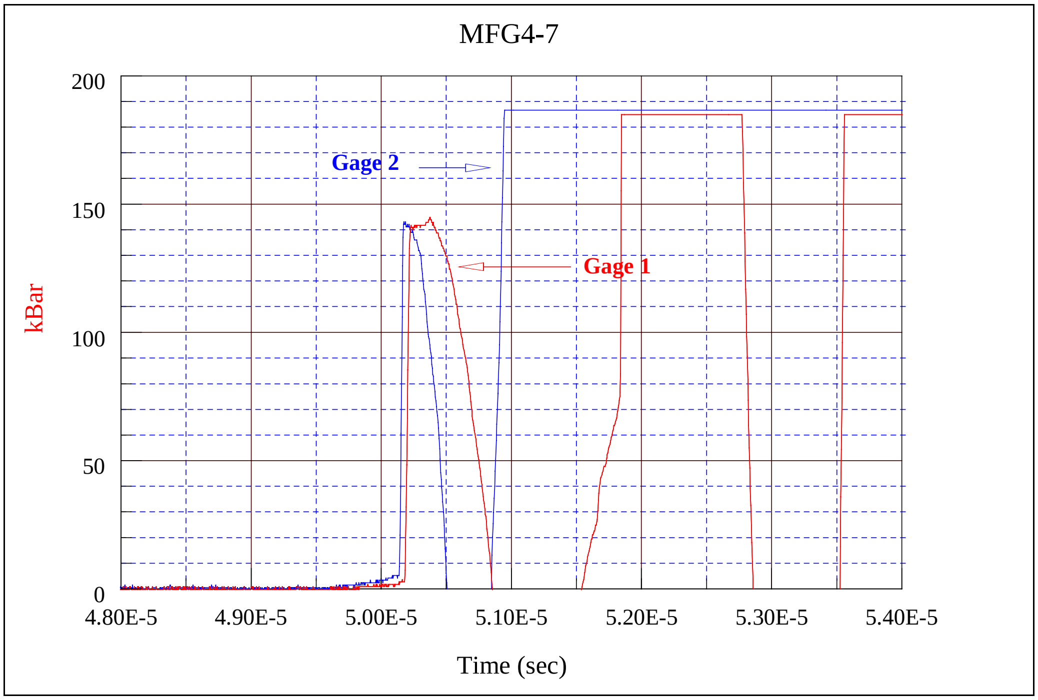


Figure 9. Gage output from new gages above 150kbar (MFG4-7).

From the data obtained it is believed that the ALOX/Z material (normally nonconductive) became conductive at high pressures, therefore causing the stripped Mn element to short. Tests were performed previously up to 100 kbar without observing this phenomenon. S. Montgomery, Neutron Generator Development Department 2561, was consulted and commented that it is possible for the EPON 828 epoxy to become conductive at pressures somewhere above 100 kbar. We believe that the data from these two shots (excluding MFG4-8 gage #2, which shorted out before reaching pressure plateau) are valid since they reached a pressure plateau before shorting occurred. Future investigation of this phenomenon may be warranted. **From the data it appears that the extension may not continue to be linear**.

Since only three data points were acquired at two pressures closely together, the new calibration curve fit in ALOX/Z from 100 to 150 kbar is approximated by a straight line. It is given below.

<u>Extended ALOX/Z 100 to 150 kbar (MAC00) calibration curve for ALOX/Z non homogeneous material</u>

For pressures between 100 and 150 kbar

$P = 4.341961\ (\Delta r/r) - 19.26188$

Where:

P is pressure in kbar

$\Delta r/r$ is change in resistance divided by the initial gage resistance in percent (the change in resistance of the Mn gage divided by the initial gage resistance, quantity times 100)

3.3.4 DQA calibration series (DQA-1, -2, -4, -5, -7, -8, -9, and -10)

The fourth set of tests, the new calibration tests (DQA-1, -2, -4, -5, -7, -8, -9, and -10) were conducted to establish performance of a new batch of Mn gages (new Mn alloy material). These gages are to be used in the production of DQAs. The results of the DQA tests are shown in Table 6 and Figures 10-13.

Table 6. DQA Calibration Series (DQA-1, -2, -4, -5, -7, -8, -9, and –10)

Test ID	Calculated Pressure (kbar) *	Target Material	Gage	Gage Readings (kbar) **	Dev. (%)
DQA-1	33.18	PMMA	1	31.5	-5.0
			2	31.4	-5.4
DQA-2	38.27	PMMA	1	36.5	-4.6
			2	36.94	-3.5
DQA-4	95.42	Al-6061	1	100.3	5.1
			2	99.3	4.1
DQA-5	92.78	Al-6061	1	96.2	3.7
			2	96.4	3.9
DQA-7	(H) 180.0 (V) ***	Sapphire	No Mn Gages used for this test. VISAR only		
DQA-8	(H) 151.3	Sapphire	1	151.0	-0.19
	(V) 151.3		2	152.4	0.76
DQA-9	152.9	Copper	1	148.7	-2.8
			2	148.1	-3.2
DQA-10	154.6	Copper	1	153.3	-0.86
			2	152.7	-1.2

Notes: * Pressure calculated from projectile velocity and Hugoniot Data.
** Pressure readings using MAC97 calibration curve.
*** Data Not used.
H Pressure calculated from projectile velocity and Hugoniot data
V Pressure calculated from VISAR and Hugoniot data.

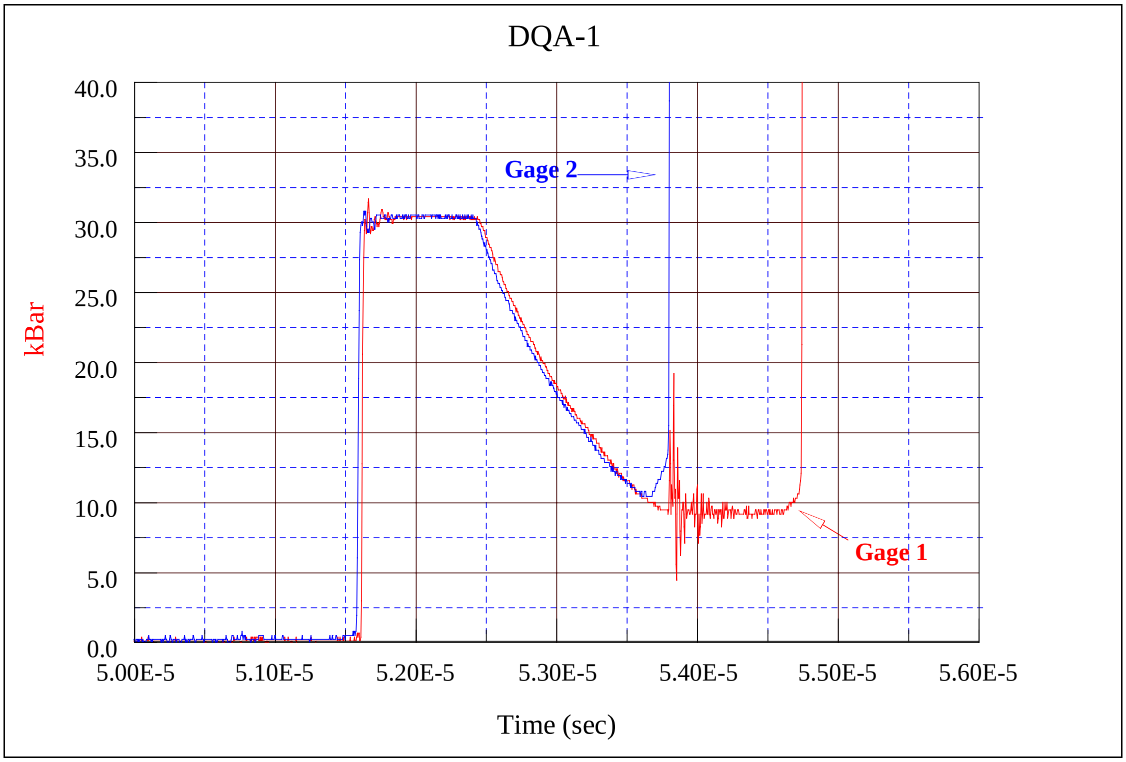


Figure 10. DQA Mn gage output for 33.2 kbar test (DQA-1)

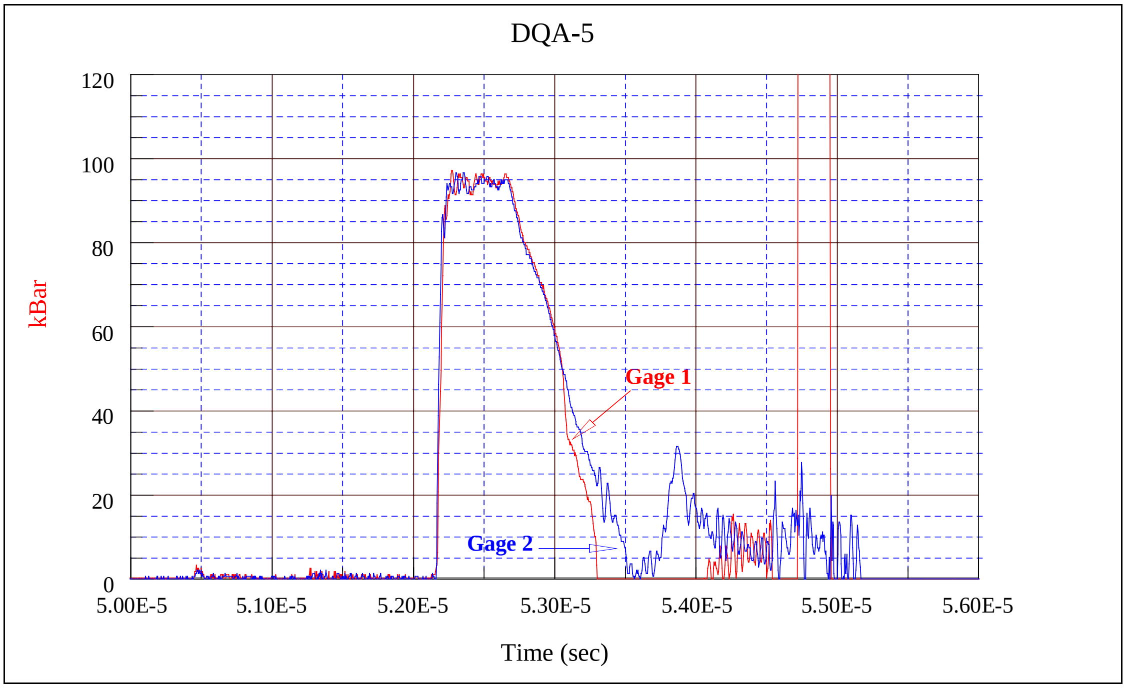


Figure 11. DQA Mn gage output for 92.8 kbar test (DQA-5)

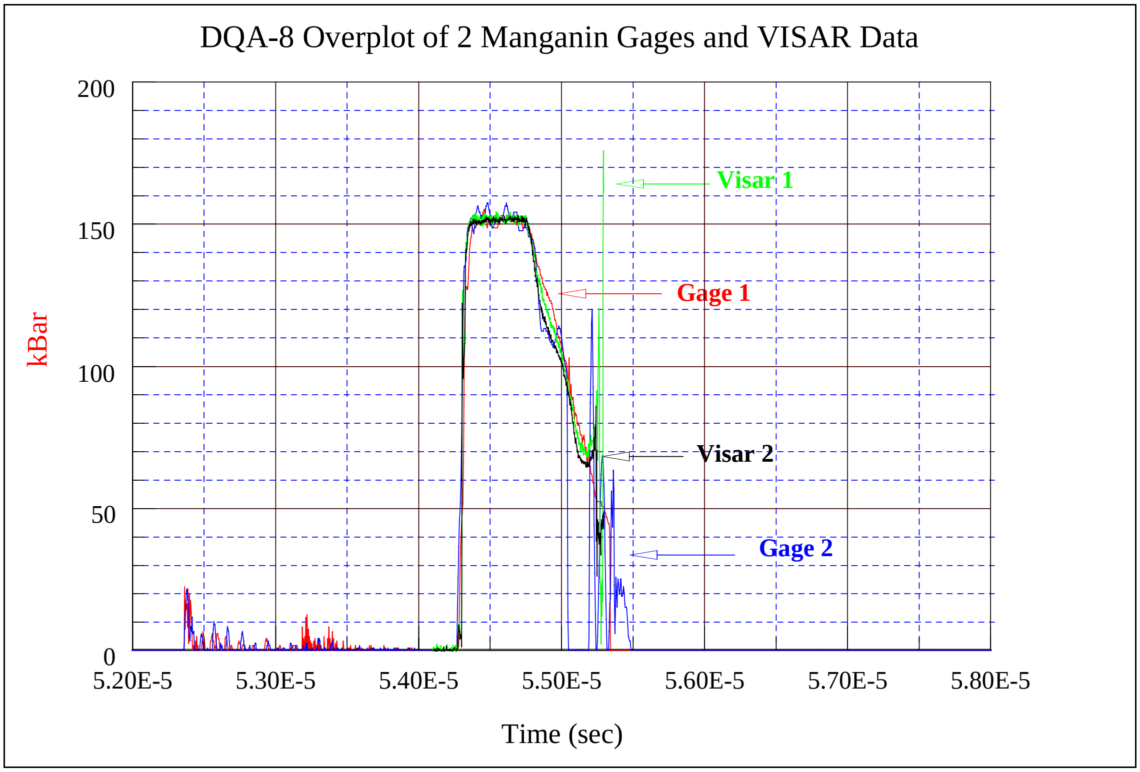


Figure 12. DQA and VISAR output for 151.3 kbar test (DQA-8)
(VISAR timing aligned with Mn gage output)

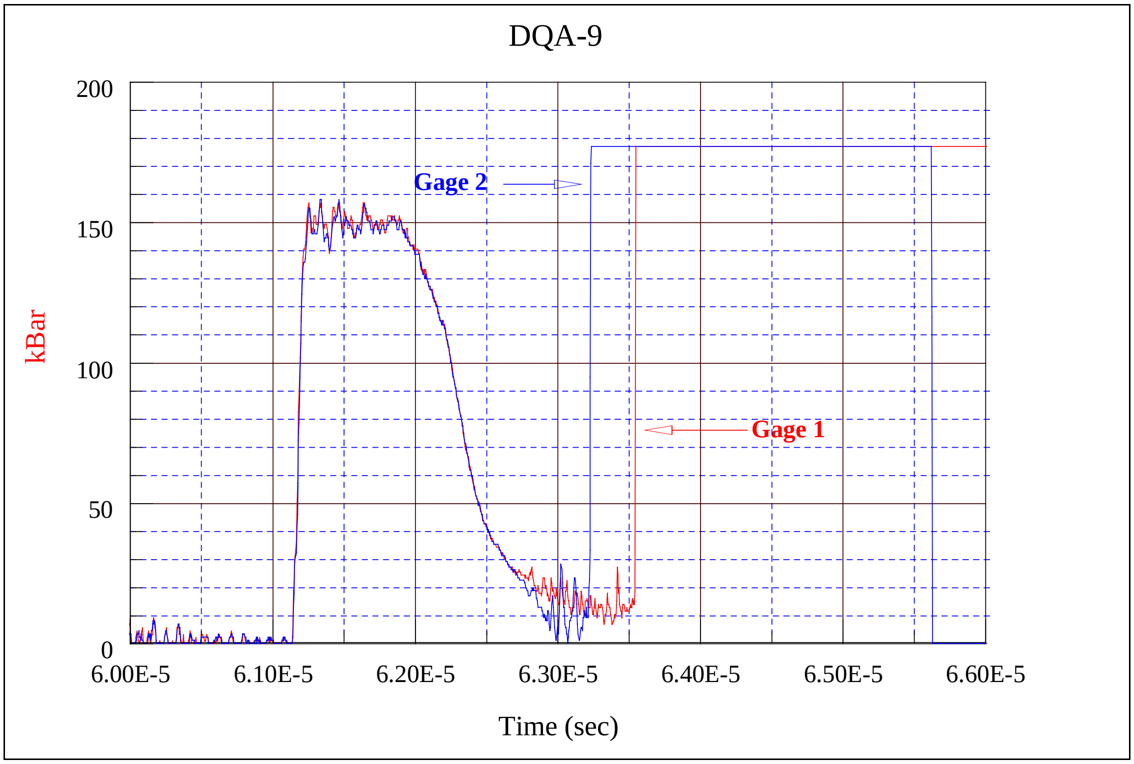


Figure 13. DQA Mn gage output for 152.9 kbar test (DQA-9)

The following observations come from this data

1) The set of data from each DQA Mn gage, at each level are very close together, showing good repeatability for the DQA Mn gages.

2) The DQA Mn gages agree well with the pressure calculation from the material Hugoniots using the known particle velocity measured from the gas gun setup prior to impact. Mn gage DQA 2000 calibration curve for homogeneous materials was developed.

3) The signals from DQA Mn gages, C-990825-A, tests DQA-1 and -2 (Table 6), produced pressures that were within – 5.4 % to -3.5 % of the gas gun delivered pressure at ~33 kbar.

4) Pressures calculated from the VISAR particle velocity measurement and from the DQA Mn gages agreed well with Hugoniot calculation on test DQA-8, as shown in Figure 12. DQA and VISAR output for 151.3 kbar test (DQA-8) Test DQA-7 had no Mn gage in place and involved only VISAR data. For an unexplained reason, the pressures calculated from the VISAR particle velocity did not match the pressure calculated from the impact velocity/hugoniot data for this test. Due to this discrepancy, the data from DQA-7 was not used.

5) The DQA 2000 calibration curve was developed for homogeneous materials. This curve coincides with the Rosenberg calibration curve between 0 and 70 kbar, and assigns a linear extension from 70 to 170 kbar. The data from the DQA series agrees well with this calibration curve.

DQA 2000 calibration curve for homogeneous materials

For pressure between 0 and 15 kbar

$$P = 5\ (\Delta r/r)$$

For pressure from 15 to 170 kbar

$$P = 4.47907 + 3.38811\,(\Delta r/r) + 0.0506272\,(\Delta r/r)^2 - .00144808\,(\Delta r/r)^3 + .0000144828\,(\Delta r/r)^4$$

Where:

P is pressure in kbar and

$\Delta r/r$ is change in resistance divided by the initial gage resistance in percent (the change in resistance of the Mn gage divided by the initial gage resistance, quantity times 100). Note that the $\Delta r/r$ has been compensated for the Wheatstone bridge non-linearity. This compensation is small for pressures less than 100 kbar. Therefore for pressures less than 100 kbar, $\Delta r/r$ can be calculated directly from voltage reading off the waveform digitizer. Also note that all $\Delta r/r$ values in this test series have been compensated. The compensation is explained in Appendix C.

Based upon the above observations, the calibration relation for the DQA Mn gages C-990325-A has been designated DQA 2000.

Figure 14 shows the data points from this test series and previous calibration test series along with Rosenberg, NDB95, MAC97, DQA 2000, and MAC00 (extended ALOX/Z 100 to 150 kbar) calibration curves.

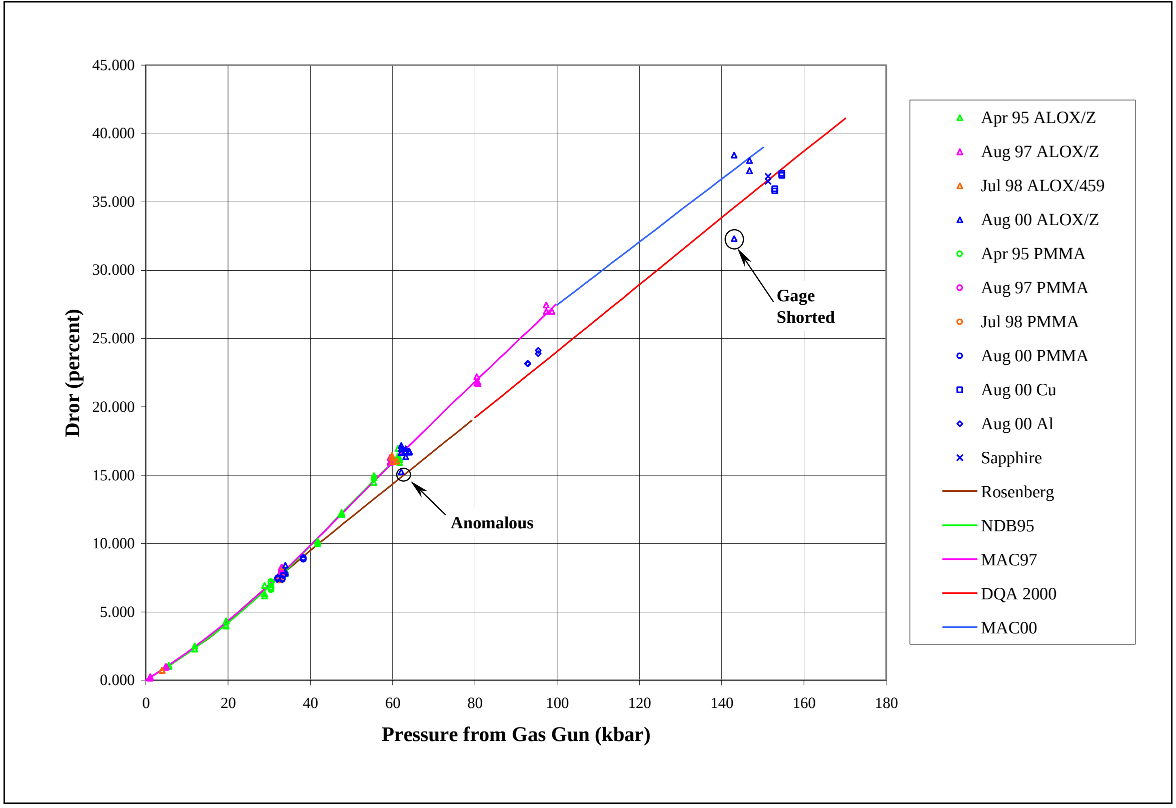


Figure 14. Mn Gage Calibration Series Data and Calibration Curves

4.0 Conclusion

In the preliminary tests the gas gun produced the desired velocities that gave 33 kbar, thus demonstrating the quality of the Gas Gun operation at the ECF.

The new MFG Mn gages pressures gave good agreement both with the pressure calculation from the Hugoniot using the particle velocity from the impact produced and previously calibrated MFG Mn gages. ***Therefore the same MAC97 Ext calibration curve (0 to 100 kbar) shall be used for the new MFG Mn gages.*** For pressures less than 100 kbar, $\Delta r/r$ can be calculated directly from voltage reading off the waveform digitizer, without any correction for bridge linearity.

A linear calibration curve fit was made for the extension of the MFG Mn gage in ALOX/Z to 150 kbar. From the data obtained it is believed that the ALOX/Z material (normally nonconductive) became conductive at the higher pressure therefore causing the stripped Mn element to short. From the data it appears that the extension may not continue to be linear and may actually approach the DQA 2000 curve.

The DQA Mn gages pressures gave good agreement both with the pressure calculation from the Hugoniot using the particle velocity from the impact produced as well as previously calibrated MFG Mn gages (in PMMA). The DQA 2000 calibration curve was developed, which coincides with the Rosenberg calibration curve with a linear extension from 30 to 170 kbar. ***Therefore the DQA 2000 calibration curve (0 to 170 kbar) shall be used for the new DQA Mn gages***

5.0 References

1. Lee, L. M., J. Appl. Phys. Vol. 44, Sept. 1973, pp 4017-4022.
2. Rosennberg, Z., et al, J.Appl. Phys. Vol 51 (7), July 1980, pp 3702-3705.
3. G. Peevy, R. Benham, W. Rivera, K. Shelton, " MC4378 Timer (W76) Manganin Foil Gage Pressure Transducer", Sandia National Laboratories, Report No. SAND2000-0996, April 2000.
4. Specification SS707932-001 Manganin Foil Gage (MFG) Pressure Transducer.
5. Hertel, E.S., “The CTH Data Interface for Equation-of-State and Constitutive Model Parameters”, Sandia National Laboratories, Report No. SAND92-1297, August 1992.
6. Matthews, J.D, Weirick, L.J, “A Hugoniot study on PMMA Manufactured by Polycast Technology Corporation”, Sandia National Laboratories, Report No. SAND90-2402, February 1991.
7. Lee, L. M., “Alumina-Filled Epoxy Shock Response as a Function of Temperature.” Air Force Weapons Laboratory Report, AFWL-TR-87-133 Sept. 1988.
8. Barnet, L.M., Hollenbach, R.E., “Shock-Wave studies of PMMA, Fused Silica, and Sapphire”, J. Appl Phys., Vol. 41 (10), September 1970.
9. Baker, L. M. and Hollenbach, R. E., “Shock-Wave Studies of PMMA, Fused Silica, and Sapphire.” J. Appl Phys. Vol. 11 (10), September 1970, pp 4208-4226.
10. Baker, L. M. and Hollenbach, R. E., “Laser Interferometer for Measuring High Velocities of Any Reflecting Surface.” J. Appl Phys., Vol. 43 (11), November 1972.
11. O. B. Crump, Jr., P. L. Stanton, “Push-Pull, Double-Delay-Leg or Dual VISAR”, Sandia National Laboratories, Report No. SAND87-1974, May 1988.
12. Schuler, K. W. and Nunziato, J. W., “The Unloading and Reloading Behavior of Shock Compressed Polymethyl Methacrylate.” J. Appl Phys. Vol. 47 (7), July 1976, pp 2995-2998.

Appendix A. Documentation of Explosives Components Department 2553 Management and Quality Engineering & Business Practices Department 14408 Concurrence of Test Plan

5. Memo, W. Rivera and G. Peevy to Distribution, dtd. 6/27/00, subject: Plan for Calibration of Additional Thin-Foil Manganin Gages and Special Tests Update
6. Memo, W. Rivera and G. Peevy to Distribution, dtd. 3/20/00, subject: Plan for Calibration of Additional Thin-Foil Manganin Gages and Special Tests
7. E-mail, G. Scharrer to W. Rivera, et el, dtd. 6/12/00, subject: Manganin Gage Calibration
8. Memo, J. Salas to G. Peevy, dtd. 8/14/97, subject: Corrections to Procedures for Gage Calibration Series
9. Memo, J. Salas to G. Peevy, dtd. 7/31/97, subject: Procedures for MFG Calibration Series

From: Scharrer, Gregory L
Sent: June 12, 2000 2:40 PM
To: Rivera, Wayne G; Peevy, Gregg R; Benham, Robert A
Cc: Tonnesen, Sandy
Subject: Manganin Gage Calibration

The procedures for performing these calibration tests will be used in their current state. Though there have been extensive changes proposed for these procedures, the changes are administrative in nature and will not affect the results obtained from the tests.

Appendix A

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation

P.O. Box 5800
Albuquerque, New Mexico 87185-

date: 8/14/97

to: Gregg Peevy MS1453 (1553)

Jim Salas

from: Jim Salas MS 1452 (1552)

subject: Corrections to Procedures for Gage Calibration Series

Ref. Memo From Jim Salas to Gregg Peevy. Subject: Procedures for MFG Calibration Series. Dated 7/31/97.

The above memo stated our intentions for utilizing operational procedures that were written for the original calibration test series of Maganin gages. Our intent is to use the same procedures in the follow on test series with corrections that will be documented in this memo and hand corrected in the original procedures. The quality engineer (Rick Crabb) has agreed that this is acceptable, and will generate the proper documentation (SIER).
The changes to the procedures are as follows:

"Manganin Gage Calibration Testing With the MC3359A/B Tester"

Page 1 - Change Div# from "2653" to "1553"
Page 3 - Change in 1.1 from Facility "922" to "905"
Change in 1.2.2 from "60 each, 48 to be tested to "32"
Add in 1.2.2 "Reference memo from Peevy to Distribution, dated June 4, 1997 "Meeting Minutes, Special Tests and Calibration of Additional Thin Foil Manganin Gages"
Page 4 - Change in 2.1 "SP472332" to "473319"
Page 4 - Change in 2.1 "922" to "905"
Page 4 - Change in 2.2 "922" to "905"
Page 4 - Change in 2.2 "2653" to "1553" "2654" to "1554" two places.
Page 5 - Change in 3.2 "EP401418" to
Page 6 - Change in 3.5 "SP47332" to "473319"
Page 6 - Change in 3.5 "922" to "905"
Page 10 - Change in 6.1 remove "strain" change "four" to "two"
Page 11 - Change in 6.3 Remove "pressure pulse duration (@1/2 amplitude)" remove "strain"
Page 12 - Change "5 - 60 kbar" to "1 - to 100 kbar"
Page 14 - Change in 7.3 step 10
Page 14 - Change in 7.3 step 15 Change "100+/-10" to "125 +/- 25" two places

Page 17 - Change in 7.4 step 20 Remove "53.0", "51.0", "49.0"
Page 24 - Change in 7.7 step 5 "SP472332" to "SP473319"
Page 25 - Change in 7.7 step 8 Remove "strain"
Page 25 - Change in 7.7 step 11 Remove "pressure pulse duration (@1/2 amplitude)"
Page 28 - Change in table remove resistance levels of "49, 51, 53" and PPS levels ".237, .701, 1.152"
Page 29 - Change in lower table remove "Resistance Decade Box (RDB), and IET Labs HARS-X-5-.01.RM)
Page 30 - Change in Table remove "Pressure pulse duration (@1/2 amplitude) remove "strain" remove columns labeled "MN Gage #3, MN Gage #4, Strain #1, and Strain #2".
Page 31 - Change in table "SP472332" to "473319"
Page 31 - Change in 7.3 change "30 minutes" to "1 hour"
Page 32 - Change in 7.4 Remove "53.0", "51.0", "49.0"
Page 33 - Change in 7.4 Remove "53.0", "51.0", "49.0"
Page 34 - Change in 7.4 Remove "53.0", "51.0", "49.0"
Page 35 - Change in 7.5 Remove "3/4" 6 places

"Calibrating The Micro-Measurements Thin-Foil Manganin Gages" ***Quality Assurance Program***

Page 4 - Change in 1.2 "2654" to "1554"
Page 4 - Change in 1.3 "Larry Weirick, Project Engineer" to Jim Salas, Principle Investigator", "Guy Dahms" to "Rick Crabb", "Mike Navaro to "Dan Sanchez", "Rick Saxton" to "Theresa Broyles"
Page 5 - Change in 2.1 change "GFE" to "furnished", "Larry Weirick to "Jim Salas"
Page 5 - Change in 2.2 change "Larry Weirick" to "Jim Salas"
Page 6 - Change in calibration dates from "8/28/95" to "2/19/98" and "7/28/95" to "8/6/98"
Page 6 - Change in *Action paragraph* change sentence to read "The particle velocity of ALOX is equal to one-half the measured projectile velocity for the symmetrical test. Non symmetrical tests will be determined by Hugoniot data.", change "Mike Navaro" to "Dan Sanchez"
Page 7 - Change first sentence in second paragraph to read "The gage output measurements are done according to OI-MC3359A-005."
Page 7 - Change in 4.1 "Larry Weirick to "Jim Salas"
Page 8 - Change in 4.3 *Action* first sentence from "a subset of three tests" to "two tests" Change second sentence to "After these tests, the data and procedural operations will be reviewed and approved by representatives of the PRT before continuing the test series."
Page 9 - Change "project engineer" to "Principle Investigator", "Larry Weirick" to "Jim Salas"
Page 10 - Change in first paragraph "2654" to "1554", "2653" to "1553"
Page 10 - Change in 5.1 "TA II, Bldg. 922, room 1" to "Bldg. 905, room 1201"
Page 10 - Change in 5.4 "TA II, Bldg. 922, room 1" to "Bldg. 905, room 1201"
Page 11 - Change in 6.1 "TA II, Bldg. 922, room 1" to "Bldg. 905, room 205"
Page 11 - Change in 6.1 "Larry Weirick" to "Jim Salas"

Page 11 - Change in 6.2 "Rick Saxton" to "Theresa Broyles", "Mike Navaro" to "Dan Sanchez"
Page 12 - Section 7 *Action paragraph.* Change first sentence to "Two recalibration tests will be done." Change last sentence to "After these tests, the data and procedural operations will be reviewed and approved by representatives of the PRT."
Page 12 - Change in 3.1 "Mike Navaro" to "Dan Sanchez"
Page 13 - Change in 3.3 "TA II, Bldg. 922, room 1" to "Bldg. 905, room 1213"
Page 13 - Change in 3.3 "Bldg. 922 Rm. 3" to Bldg. 905 Rm. 1201
Page 13 - Change "Rick Saxton" to "Theresa Broyles"
Page 13 - Change in 3.3 *Action paragraph* change last sentence to read "The tester has been EQ certified."
Page 13 - Change in 8.1 "2654" to "1554"
Page 13 - Change in 8.2 "Rick Saxton" to "Theresa Broyles" 2 places.

"Procedures for Assembly of Velocity Pin Block"

Change cover sheet "Process Engineer" from "Larry Weirick and Mike Navaro" to "Dan Sanchez"

"Assembly Procedures for Calibration of the Thin Foil, Manganin Gage (MFG-K) Pressure Transducer (U)"

Change cover sheet - Delete "Larry Weirick" from Process Engineer, Replace "Rick Crabb" for "Guy E. Dahms"
Change - 6.4 from "four" to "two"
Change - Calibration Testing Of Manganin Foil Gages Approval list, replace "Lawrence J. Weirick" to "Jim Salas" and "Guy Dahms" to "Rick Crabb"
Change - Travelers and forms Heidi will generate changes.

"Installation Procedures and Data Recording for the Time Interval Meter Used for Calibrating the Thin-Foil Manganin Gage."

Change in Control Section from Michael Navaro to Dan Sanchez signature.
Change in Equipment paragraph "922" to "905", "3000 psi" to "3950 psi", "644A Oscilloscope" to "744A Digitizer"
Change in Materials paragraph from "Helium" to "Helium, Nitrogen"
Change in document section from "14A087" to "15A007"
Change in page 2 - paragraph one from "922" to "905", from "SOP SP472332...approved on 7/25/94" to "SP473319...approved on 9/11/96, and OP-905-0021, the Light Gas Gun Operating Procedure.
Change in Page 2 - paragraph Starting "The projectile is loaded into the breach.... Change "SP472332" to "SP473319", delete words "or wraparound" in second sentence, change from "50 millitorr" to "500 millitorr".
Change in page 2 - second to last paragraph from "SP472332" to "SP473319"
Change in page 2 - last paragraph from "oscilloscopes" to "digitizers", "15 millitorr" to "70 millitorr".

Change in Shot Sheet Form - Replace with new form "Appendix B: Pre-Shot Planning Form" from OP905-0021

Change in last page - Replace "Shot Matrix Sheet" with matrix of new series.

Copy to:

MS-1454	R. A. Benham
MS-1453	B. D. Duggins
MS-1453	R. L. Crabb
MS-1454	D. H. Sanchez
MS-1454	H. M. Anderson
MS-1454	T. A. Broyles

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

P.O. Box 5800
Albuquerque, New Mexico 87185-

date: 7/31/97

to: Gregg R. Peevy, MS-1453 (1553)

from: Jim Salas, MS-1452 (1552)

subject: Procedures for MFG calibration series.

Several operational procedures were written for the calibration series of Micro-Measurement (M-M) manganin gages. This original test series was conducted in April of 1995 in area II, building 922. A follow on calibration and extended calibration series of these gages will be conducted using the light gas gun facility in Bldg. 905 in August of 1997. This follow on test series will utilize the same operational procedures that were used in the original test series.

Minor changes will be made to the procedures listed below, and are primarily due to the location change, and personnel changes since the last test series. Any specific changes to these procedures that may be more in scope than name or building changes will be reviewed and approved by the appropriate personnel specifically the product engineer Robert A. Benham and the quality engineer Rick Crabb.

The procedures that will be used are listed below:

"Manganin Gage Calibration Testing with the MC3359A/B Tester" Doc. No. OIMC3359A/B-005

"Installation Procedures and Data Recording for the Time Interval Meter Used for Calibrating the Thin-Foil Manganin Gage" Doc. No. OP-GUAT922.1 Issue A

"Assembly Procedures for Calibration of the Thin-Foil, Manganin Gage (MFG-K) Pressure Transducer (U)" Doc. No. OP-HAT922.1 Issue A

"Procedures for Assembly of Velocity Pin Block" Doc. No. OP-VPAT922.1 Issue A

"Calibration the Micro-Measurements Thi-Foil Maganain Gages" *Quality Assurance Program* Doc. No. 922-5001-311

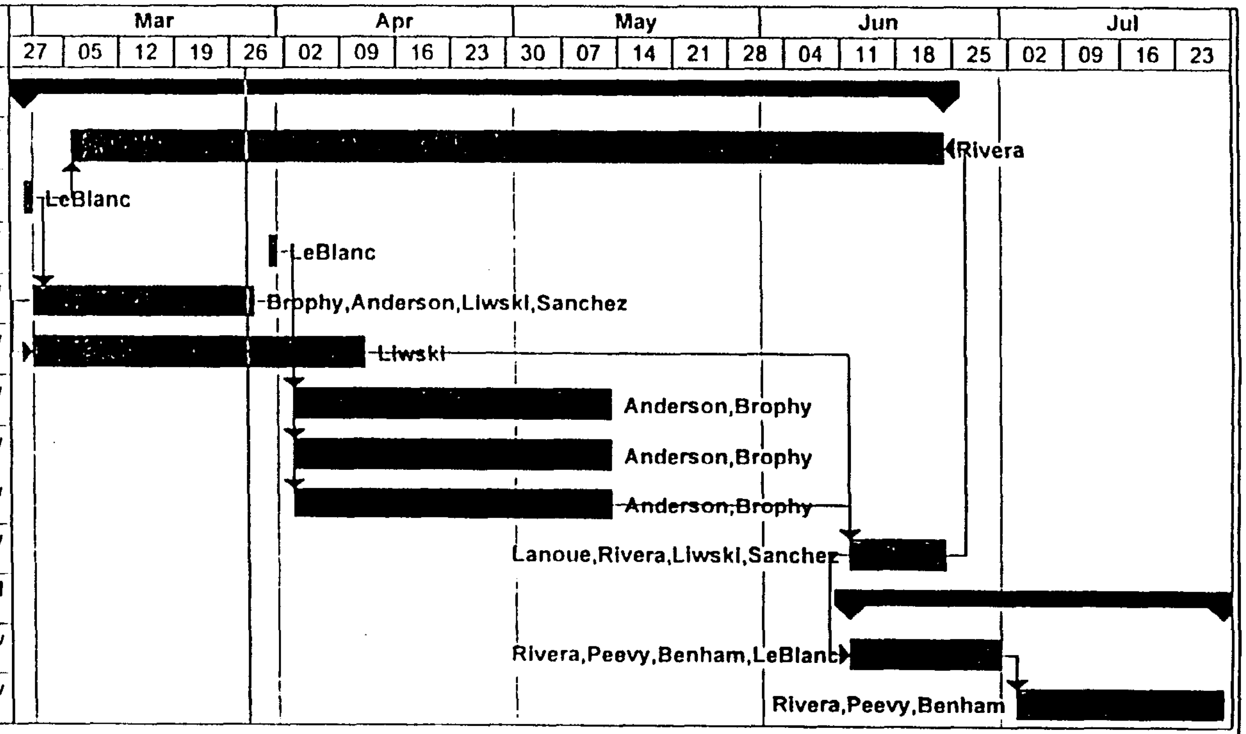
Due to the cost effectiveness of re-writing these documents, we are proposing using hand corrected versions of these documents for this test series. Discussions with our quality representative and line management will determine if this approach is reasonable.

Changes to the procedures will be documented in a forthcoming memo. Once the corrected versions of these documents are completed, the quality representative will generate the appropriate documentation needed for implementing them into the system.

Copy to:

MS-1453	F. H. Braaten
MS-1454	L. L. Bonzon
MS-1452	J. G. Harlan
MS-1454	R. A. Benham
MS-1453	B. D. Duggins
MS-1453	R. L. Crabb
MS-1454	D. H. Sanchez
MS-1454	H. M. Anderson
MS-1454	T. A. Broyles

ID	Task Name	Duration
1	**Test series**	84d
2	Test coordination	16w
3	Provide additional thin-foil gages	1d
4	Provide DQA thin-foil gages	1d
5	Material procurement	4w
6	Gas gun setup	6w
7	Build additional gage units (8 units for 6 tests)	6w
8	Build DQA gage units (10 units for 8 tests)	6w
9	Build extend cal units (3 units for 2 tests)	6w
10	Perform tests using gas gun (16 tests total)	2w
11	**Document test series**	35d
12	Analyze data	3w
13	Write formal SAND report	4w



Project: Cal of additional gages and sp
Date: Tue 03/28/00

Task		Summary		Rolled Up Progress	
Progress		Rolled Up Task			
Milestone		Rolled Up Milestone			

Appendix A

Operated for t
Sandia Corporation

Albuquerque, New Mexico 87185-1453

date: June 27, 2000

to: Distribution

W Gary R. Gregg R. Peevy

from: W. Gary Rivera and Gregg R. Peevy, MS-1453 (2553)

subject: Plan for Calibration of Additional Thin-Foil Manganin Gages and Special Tests Update

Ref. 1. Memo, W. Rivera and G. Peevy to Distribution, dtd. 3/20/00, subject: Plan for Calibration of Additional Thin-Foil Manganin Gages and Special Tests
2. E-mail, G. Scharrer to W. Rivera, et el, dtd. 6/12/00, subject: Manganin Gage Calibration
3. Memo, J. Salas to G. Peevy, dtd. 8/14/97, subject: Corrections to Procedures for Gage Calibration Series
4. Light-Gas Gun Operating Procedure, OP-905-0021, Issue C, dtd. 6/30/97

This memo is to update the plan for calibration of additional Manganin thin-foil gages and special tests described in Reference 1 and to document Explosives Components Department 2553 management and Quality Engineering & Business Practices Department 14408 concurrence with the test plan. Department 2553 management has stated that "The procedures for performing these calibration tests will be used in their current state. Though there have been extensive changes proposed for these procedures, the changes are administrative in nature and will not affect the results obtained from the tests", see Reference 2. Attached are a revised table summarizing the tests and material properties table for Hugoniot code shock calculations. Test conducted will be technically identically to the previous test series performed in July and August 1997 with the exception that some tests will be performed at higher pressures (120 – 150 kbar) to extend the gage calibration curves for ALOX/Z (Manganin Thin-Foil Gage Pressure Transducer – MFG) and PMMA (Driver Qualification Assembly – DQA). Test setup, procedures, and calculation methods are the same from the previous test. Note that the procedure for producing and measuring test specimen flatness has been upgraded.

The following documents with red lined corrections per Reference 3 will be scanned into the Sandia National Laboratories document management system, Product Data Management (PDM) or Image Management System (IMS), by T. Garcia for document control.

1. "Manganin Gage Calibration Testing with the MC3359A/B Tester" Doc. No. OI-MC3359A/B-005 Issue A dated 3/22/95

2. "Installation Procedures and Data Recording for the Time Interval Meter Used for Calibrating the Thin-Foil Manganin Gage" Doc. No. OP-GUAT922.1 Issue A dated 3/30/95
3. "Assembly Procedures for Calibration of the Thin-Foil Manganin Gage (MFG-K) Pressure Transducer (U)" Doc. No. OP-HAT922.1 Issue A dated 3/31/95
4. "Procedures for Assembly of Velocity Pin Block" Doc. No. OP-VPAT922.1 Issue A dated 3/30/95
5. "Calibrating the Micro-Measurements Thin-Foil Manganin Gages" Quality Assurance Program Doc. No. 922-5001-311 Issue B dated 4/12/95

The Light-Gas Gun used to perform the calibration test series will be operated using the current Building 905 Explosives Components Facility (ECF) operating procedures, see Reference 4.

This memo along with the following memos will be included in a data package to be submitted to IMS for archival. This will be to document the test plan and the administrative changes.

- Memo, W. Rivera and G. Peevy to Distribution, dtd. 3/20/00, subject: Plan for Calibration of Additional Thin-Foil Manganin Gages and Special Tests
- Memo, J. Salas to G. Peevy, dtd. 8/14/97, subject: Corrections to Procedures for Gage Calibration Series
- Memo, J. Salas to G. Peevy, dtd. 7/31/97, subject: Procedures for MFG Calibration Series

A gage calibration test readiness review was held with Management and Quality on June 27. Management and Quality concurrence to proceed with the test series as defined in this memo and Reference 1 is given below.

Gregory L. Scharrer Explosives Components Department 2553 Management Concurrence	Sandra L. Tonnesen Quality Engineering & Business Practices Department 14408 Concurrence

Attachments

- Revised Calibration of Additional Thin-Foil Manganin Gages and Special Test Summary Table
- Material Properties Table for Hugoniot code shock calculations

GRP/grp

Copy to:

MS-1453	Robert A. Benham, 2553
MS-1453	Paul Brophy, 2553
MS-1453	Toby L. Garcia, 2553
MS-1453	Roy F. LeBlanc, 2553
MS-1453	Gregg R. Peevy, 2553
MS-1453	W. Gary Rivera, 2553
MS-1453	Gregory L. Scharrer, 2553
MS-1453	Terry M. Witt, 2553
MS-1453	Sandra L. Tonneson, 14408
MS-1454	Heidi M. Anderson, 2554
MS-1454	Lloyd L. Bonzon, 2554
MS-1454	John C. Lanoue, 2554
MS-1454	John F. Liwski, 2554
MS-1454	Daniel H. Sanchez, 2554
MS-1453	Day File, 2553

Test Description and Serial nos.	# Tests	Impactor Material	Impactor Dia. (in.)	Impactor Thk. (in.)	Buffer Mat'l	Buffer Dia. (in.)	Buffer Thk. (in.)	Target Mat'l	Target Dia. (in.)	Target Thk. (in.)	Projectile Impact Velocity (mm/us)	Particle Velocity Up (mm/us)	Pressure (kbar)	Calc.	Notes
Set-up MFG4-SU1 MFG4-SU2	2	PMMA (Rhom and Haas)	2.00	0.10	PMMA (Rhom and Haas)	2.00	0.10	PMMA (Rhom and Haas)	2.00	1.00	1.492	0.746	33.0	H	A, 1
Cal for MFG MFG4-1 MFG4-2 MFG4-3 (spare unit)	2	ALOX/Z	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	0.778	0.389	33.0	H	A, 1, 2
Cal for MFG MFG4-4 MFG4-5 MFG4-6 (spare parts)	2	ALOX/Z	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	1.267	0.633	61.0	H	A, 1, 2
Cal for DQA DQA-1 DQA-2 DQA-3 (spare parts)	2	PMMA (Rhom and Haas)	2.00	0.10	PMMA (Rhom and Haas)	2.00	0.10	PMMA (Rhom and Haas)	2.00	1.00	1.492	0.746	33.0	H	A, 1
Cal for DQA DQA-4 DQA-5 DQA-6 (spare parts)	2	Aluminum 6061-T651	2.00	0.10	Aluminum 6061-T651	2.00	0.20	Aluminum 6061-T651	2.00	1.00	1.150	0.575	95.1	H	B, 1
Cal for DQA Check perf. DQA-7 DQA-8	2	Aluminum 6061-T651	2.00	0.10	Aluminum 6061-T651	2.00	0.20	Sapphire	2.00	0.50	1.178	0.473	119.9	H	B, 3
Cal for DQA DQA-9 DQA-10	2	Copper	2.00	0.10	Copper	2.00	0.20	Copper	2.00	0.80	0.763	0.382	152.6	H	B, 1
Ext cal for MFG MFG4-7 MFG4-8 MFG4-9 (spare parts)	2	Copper	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	1.492	1.147	137.6	H	A, 1

Cal. Calculation: H = Hugoniot code

General notes:

2 gages on target, positioned 180 degrees apart (H. Anderson to build specimens)

Provide pins for velocity and tilt

Calibrating to equilibrium pressure (flat pulse greater than 0.5 us long)

Provide pin for UA6613 Tester trigger

Gage mounted between buffer and target

Spare unit is a fully assembled unit

Up = projectile impact velocity / 2

Specific notes:

(A) Mn gage stripped

(B) Mn gage not stripped and insulated from metal surface with 1 mil thick kapton

(1) Match particle velocity as closely as possible

(2) Include two previously calibrated gages to verify new ALOX material properties - 4 gages total

(3) VISAR measurement to verify technique
No Mn gages on DQA-7 (VISAR only)
2 Mn gages on DQA-8 plus VISAR

Material	Density rho (g/cc)	c0 (mm/us)	s
PMMA (March, 1980)	1.186	2.598	1.516
ALOX (Lee, 1981)	2.375	2.807	1.972
Sapphire	4.022	1.000	11.19
Aluminum	2.703	5.350	1.340
Copper	8.920	3.910	1.510

P(GPa) = rho * up * (c0 + s * up)

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-1453

date: March 20, 2000

to: Distribution

from: W. Gary Rivera, MS-1453 (2553) Gregg R. Peevy, MS-1453 (2553)

subject: Plan for Calibration of Additional Thin-Foil Manganin Gages and Special Tests

Ref. Memo, W. Rivera to G. Scharrer, dtd. 12/17/99, subject: Request of Funds for Calibration of Additional Thin-Foil Manganin Gages and Special Tests

This memo is to document the plan for calibration of additional Manganin thin-foil gages and special tests per the referenced document. A table summarizing the tests is attached. A Gantt chart scheduling the test activities is also attached. Personnel to be involved are listed in the Gantt chart. Time and expenditures for this activity are to be spread across the four Timer project/task numbers: 7956 01.01, 7954 01.02, 7954 01.05, 7954 01.09. Specific quality and documentation activities are listed below. G. Rivera is responsible for ensuring these activities are accomplished. P. Brophy is responsible for assembling documentary notebooks.

- The gages will be delivered to a 2553 person.
- The gages should be given directly to a trained MFG tester operator for logging into a production storage cabinet. J. Lanoue.
- All of these gages need to be controlled throughout their Sandia travel to preserve the material quality required to place these in bonded stores after they are accepted by our tests.
- All of the material shall be kept under positive control until transferred to bonded stores.
- A notebook with all of the documents and records of the calibration process shall be kept for each calibration series (DQA & MFG). P. Brophy.
- The "Letter of Conformance" should accompany each lot of gages, these letters shall be given to P. Brophy and kept in the notebook with the records for each of the calibration processes. R. LeBlanc.
- Schedule Tests, see Test plan, meet with Gas Gun project leader (J. Liwski) to communicate requirements. G. Rivera.
- Schedule fabrication of the gage targets, obtain sketches of hardware to match with the Test Plan. P. Brophy.
- Gas gun hardware drawings will be released in Sandia Image Management System. Material certifications and inspection reports are not required.
- Formally, randomly (Record method used and results) select the proper number of gages for each series of tests and transfer them to the production locker and care of the fabricator.
- Keep the remainder of the gages in the initial production storage location. Don't mix the two different lots of gages.

- Fabricate targets and document the process. H. Anderson.
- Material certifications required on impactor, buffer, and target materials. P. Brophy.
- Obtain finished targets and documentation notebook. P. Brophy
- Transfer targets to the Gas Gun Project lead for proper controlled storage. H. Anderson and J. Liwski.
- Conduct trial test and compare with expected results (past tests and Kowin calculations if possible). Team and G. Rivera.
- Data recorded on UA6613 Tester. Datasheets and files will be collected in notebook for archive. J. Lanoue and P. Brophy.
- When all OK then proceed with the individual test series per agreed upon plan.
- Finish tests and gather all documents. P. Brophy.
- For MFG gages, if the results match previous data, document results and send to bonded stores using the same manufacturers part number as gages already in stores using PMQP. If different results document and send to bonded stores under a different # (along with the calibration information).
- For the DQA gages document the results and send to bonded stores under a unique Sandia drawing number for DQA parts using PMQP.
- Prepare a summary letter with important results to be sent to interested users and include the front page of each documentary notebook. G. Rivera.
- Place each notebook in archives in 905, room 205. P. Brophy.
- All activities must have concurrence with Quality Engineering Department 14408.
- Gages will be logged into bonded stores through the PMQP process following calibration tests. B. Bowles.
- Procedures for the conduct of these calibration tests are listed below:
  Memo, J. Salas to G. Peevy, dtd. 8/14/97, subject: Corrections to Procedures for Gage Calibration Series.
  Memo, J. Salas to G. Peevy, dtd. 7/31/97, subject: Procedures for MFG Calibration Series.

Please call us if you have any questions.

GRP/grp

Copy to:

MS-1453	Robert A. Benham, 2553
MS-1453	Carl F. Brezowski, 2553
MS-1453	Paul Brophy, 2553
MS-1453	Toby L. Garcia, 2553
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MS-1453	Day File, 2553

Test Description and Serial nos.	# Tests	Impactor Material	Impactor Dia. (in.)	Impactor Thk. (in.)	Buffer Mat'l	Buffer Dia. (in.)	Buffer Thk. (in.)	Target Mat'l	Target Dia. (in.)	Target Thk. (in.)	Projectile Impact Velocity (mm/us)	Particle Velocity (mm/us)	Pressure (kbar)	Calc.	Notes
Set-up MFG4-SU1 MFG4-SU2	2	PMMA (Rhom and Haas)	2.00	0.10	PMMA (Rhom and Haas)	2.00	0.10	PMMA (Rhom and Haas)	2.00	1.00	1.492	0.746	33	K	A, 1
Cal for MFG MFG4-1 MFG4-2 MFG4-3 (spare)	2	ALOX/Z	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	0.778	0.389	33	K	A, 1
Cal for MFG MFG4-4 MFG4-5 MFG4-6 (spare)	2	ALOX/Z	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	1.267	0.633	61	K	A, 1
Cal for DQA DQA-1 DQA-2 DQA-3 (spare)	2	PMMA (Rhom and Haas)	2.00	0.10	PMMA (Rhom and Haas)	2.00	0.10	PMMA (Rhom and Haas)	2.00	1.00	1.492	0.746	33	K	A, 1
Cal for DQA DQA-4 DQA-5 DQA-6 (spare)	2	Aluminum 6061-T651	2.00	0.10	Aluminum 6061-T651	2.00	0.20	Aluminum 6061-T651	2.00	1.00	1.150	0.575	92.2	K	B, 1
Cal for DQA Check perf. DQA-7 DQA-8	2	Aluminum 6061-T651	2.00	0.10	Aluminum 6061-T651	2.00	0.20	Sapphire	2.00	0.50	1.178	0.473	119.9	H	B, 2
Cal for DQA DQA-9 DQA-10	2	Copper	2.00	0.10	Copper	2.00	0.20	Copper	2.00	0.80	0.763	0.382	149	K	B, 1
Ext cal for MFG MFG4-7 MFG4-8 MFG4-9 (spare)	2	Copper	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	1.492	1.147	138	H	A, 1

Cal. Calculation: K = Kowin 1-D shock wave propagation code; H = Hugoniot code

General notes:

2 gages on target, positioned 180 degrees apart (H. Anderson to build specimens)

Provide pins for velocity and tilt

Calibrating to equilibrium pressure (flat pulse greater than 0.5 us long)

Provide pin for UA6613 Tester trigger

Gage mounted between buffer and target

Specific notes:

(A) Mn gage stripped

(B) Mn gage not stripped and insulated from metal surface with 1 mil thick kapton

(1) Match particle velocity as closely as possible

(2) VISAR measurement to verify technique

No Mn gages on DQA-7 (VISAR only)

2 Mn gages on DQA-8 plus VISAR

Appendix B. Data Details for Current and Previous Test Series

- Test Results
- Table B.1 Calibration of Additional Thin-Foil Manganin Gages and Special Test Plan.
- Table B.2 Test Series Data.
- Table B.3 Comparison of PMMA Gas Gun Tests Done in 1995, 1997, 1998, and 2000.
- Table B.4 Comparison of ALOX Gas Gun Tests Done in 1995, 1997, 1998, and 2000.
- Table B.5 Previous Calibration Test Series Data

Table B.1 Calibration of Additional Thin-Foil Manganin Gages and Special Test Plan

Test Description and Serial nos.	# Tests	Impactor Material	Impactor Dia. (in.)	Impactor Thk. (in.)	Buffer Mat'l	Buffer Dia. (in.)	Buffer Thk. (in.)	Target Mat'l	Target Dia. (in.)	Target Thk. (in.)	Projectile Impact Velocity (mm/us)	Particle Velocity Up (mm/us)	Pressure (kbar)	Calc.	Notes
Set-up MFG4-SU1 MFG4-SU2	2	PMMA (Polycast SAND90-2402)	2.00	0.10	PMMA (Polycast SAND90-2402)	2.00	0.10	PMMA (Polycast SAND90-2402)	2.00	1.00	1.492	0.746	33.0	H	A, 1
Cal for MFG MFG4-1 MFG4-2 MFG4-3 (spare unit)	2	ALOX/Z	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	0.778	0.389	33.0	H	A, 1, 2
Cal for MFG MFG4-4 MFG4-5 MFG4-6 (spare parts)	2	ALOX/Z	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	1.267	0.633	61.0	H	A, 1, 2
Cal for DQA DQA-1 DQA-2 DQA-3 (spare parts)	2	PMMA (Polycast SAND90-2402)	2.00	0.10	PMMA (Polycast SAND90-2402)	2.00	0.10	PMMA (Polycast SAND90-2402)	2.00	1.00	1.492	0.746	33.0	H	A, 1
Cal for DQA DQA-4 DQA-5 DQA-6 (spare parts)	2	Aluminum 6061-T651	2.00	0.10	Aluminum 6061-T651	2.00	0.20	Aluminum 6061-T651	2.00	1.00	1.150	0.575	95.1	H	B, 1
Cal for DQA Check perf. DQA-7 DQA-8	2	Aluminum 6061-T651	2.00	0.10	Aluminum 6061-T651	2.00	0.20	Sapphire	2.00	0.50	1.190	0.330	151.3	H	B, 3
Cal for DQA DQA-9 DQA-10	2	Copper	2.00	0.10	Copper	2.00	0.20	Copper	2.00	0.80	0.763	0.382	152.6	H	B, 1
Ext cal for MFG MFG4-7 MFG4-8 MFG4-9 (spare parts)	2	Copper	2.00	0.10	ALOX/Z	2.00	0.10	ALOX/Z	2.00	1.00	1.565	1.196	146.8	H	A, 1

Cal. Calculation: H = Hugoniot code

General notes:

2 gages on target, positioned 180 degrees apart (H. Anderson to build specimens)

Provide pins for velocity and tilt

Calibrating to equilibrium pressure (flat pulse greater than 0.5 us long)

Provide pin for UA6613 Tester trigger

Gage mounted between buffer and target

Spare unit is a fully assembled unit

Up = projectile impact velocity / 2 (except for DQA-7 & 8, MFG-7 & 8)

Specific notes:

(A) Mn gage stripped

(B) Mn gage not stripped and insulated from metal surface with 1 mil thick kapton

(1) Match particle velocity as closely as possible

(2) Include two previously calibrated gages to verify new ALOX material properties - 4 gages total

(3) VISAR measurement to verify technique
No Mn gages on DQA-7 (VISAR only)
2 Mn gages on DQA-8 plus VISAR

Calibration of additional thin foil manganin gages and special tests modified Jun 20 2000.xls, 12/04/2000

Table B.2 Test Series Data

Order	Test Date	Test	Gage Info (1)	Buffer Material (2)	Projectile Impact Velocity (mm/us)	Pressure from Hugoniot (kbar)	Fit	Gage Pressure (kbar)	Dev.^ (%)	Cable Res. (ohms)	Initial Peak Voltage (V)	Dror* (%)	Max Tilt (mRad)	PS
1	07/25/00	MFG4-SU1 #1	MFG	PMMA	1.456	32.04	2	31.571	-1.46	1.17	0.812	7.430	10.57	
		MFG4-SU1 #2	MFG	PMMA	1.456	32.04	2	31.785	-0.80	1.267	0.816	7.490		
2	07/25/00	MFG4-SU2 #1	MFG	PMMA	1.501	33.37	2	32.494	-2.62	1.106	0.840	7.690	9.71	
		MFG4-SU2 #2	MFG	PMMA	1.501	33.37	2	32.423	-2.83	1.208	0.837	7.670		
3	07/26/00	DQA-1 #1 Cal	DQA	PMMA	1.4946	33.18	2	31.535	-4.95	1.03	0.812	7.420	3.06	
		DQA-1 #2 Cal	DQA	PMMA	1.4946	33.18	2	31.392	-5.38	0.99	0.809	7.380		
4	07/27/00	DQA-2 #1 Cal	DQA	PMMA	1.6615	38.27	2	36.499	-4.63	1.2	0.959	8.840	19.74	
		DQA-2 #2 Cal	DQA	PMMA	1.6615	38.27	2	36.944	-3.46	1.16	0.973	8.970		
5	07/31/00	DQA-9 #1 Perf.	DQA	Cu	0.7601	152.9	1	148.664	-2.79	1.27	3.460	35.960	5.27	
		DQA-9 #2 Perf.	DQA	Cu	0.7601	152.9	1	148.048	-3.19	1.06	3.460	35.810		
6	07/31/00	DQA-10 #1 Perf.	DQA	Cu	0.7677	154.6	1	153.312	-0.86	1.13	3.560	37.090	2.08	
		DQA-10 #2 Perf.	DQA	Cu	0.7677	154.6	1	152.735	-1.24	0.95	3.560	36.950		
7	08/01/00	DQA-4 #1 Cal	DQA	Al 6061-T651	1.1658	95.42	1	100.318	5.14	1.08	2.45	24.140	3.46	
		DQA-4 #2 Cal	DQA	Al 6061-T651	1.1658	95.42	1	99.330	4.10	1.04	2.43	23.900		
8	08/01/00	DQA-5 #1 Cal	DQA	Al 6061-T651	1.1373	92.78	1	96.199	3.69	1.3	2.349	23.140	2.38	
		DQA-5 #2 Cal	DQA	Al 6061-T651	1.1373	92.78	1	96.405	3.91	1.2	2.358	23.190		
9	08/02/00	MFG4-1 #1 Cal	MFG	ALOX/Z	0.7952	33.91	2	33.446	-1.37	1.28	0.865	7.960	4.77	
		MFG4-1 #2 Cal	MFG	ALOX/Z	0.7952	33.91	2	33.164	-2.20	1.04	0.861	7.880		
		MFG4-1 #3 Cal	PC	ALOX/Z	0.7952	33.91	2	32.988	-2.72	1.17	0.854	7.830		S
		MFG4-1 #4 Cal	PC	ALOX/Z	0.7952	33.91	2	35.050	3.36	1.27	0.914	8.420		S
10	08/02/00	MFG4-2 #1 Cal	MFG	ALOX/Z	0.7683	32.52	2	32.777	0.79	1.14	0.847	7.770	10.21	
		MFG4-2 #2 Cal	MFG	ALOX/Z	0.7683	32.52	2	32.706	0.57	1.03	0.847	7.750		
		MFG4-2 #3 Cal	PC	ALOX/Z	0.7683	32.52	2	31.321	-3.69	1.30	0.802	7.360		S
		MFG4-2 #4 Cal	PC	ALOX/Z	0.7683	32.52	2	32.847	1.00	1.33	0.847	7.790		S

Ext cal of manganin gage July 17 00.xls

Table B.2 Test Series Data

Order	Test Date	Test	Gage Info (1)	Buffer Material (2)	Projectile Impact Velocity (mm/us)	Pressure from Hugoniot (kbar)	Fit	Gage Pressure (kbar)	Dev.^ (%)	Cable Res. (ohms)	Initial Peak Voltage (V)	Dror* (%)	Max Tilt (mRad)	PS
11	08/03/00	MFG4-4 #1 Cal@	MFG	ALOX/Z	1.2831	62.05	2	57.741	-6.94	1.16	1.608	15.260	3.10	S
		MFG4-4 #2 Cal	MFG	ALOX/Z	1.2831	62.05	2	62.398	0.57	1.33	1.740	16.670		S
		MFG4-4 #3 Cal	PC	ALOX/Z	1.2831	62.05	2	64.062	3.25	1.18	1.794	17.170		
		MFG4-4 #4 Cal	PC	ALOX/Z	1.2831	62.05	2	63.296	2.01	1.23	1.770	16.940		
12	08/03/00	MFG4-5 #1 Cal	MFG	ALOX/Z	1.3012	63.20	2	62.697	-0.79	1.05	1.758	16.760	1.46	S
		MFG4-5 #2 Cal	MFG	ALOX/Z	1.3012	63.20	2	62.664	-0.84	1.20	1.752	16.750		
		MFG4-5 #3 Cal	PC	ALOX/Z	1.3012	63.20	2	63.296	0.16	1.22	1.770	16.940		S
		MFG4-5 #4 Cal	PC	ALOX/Z	1.3012	63.20	2	61.370	-2.89	1.34	1.710	16.360		
13	08/04/00	MFG4-7 #1 Cal	MFG	ALOX/Z	1.5646	146.8	3	145.863	-0.61	0.76	3.66	38.030	6.41	
		MFG4-7 #2 Cal	MFG	ALOX/Z	1.5646	146.8	3	142.650	-2.80	1.39	3.56	37.290		
14	08/07/00	MFG4-8 #1 Cal	MFG	ALOX/Z	1.5334	143.0	3	147.600	3.18	1.27	3.66	38.430	7.89	
		MFG4-8 #2 Cal$	MFG	ALOX/Z	1.5334	143.0	3	120.983	-15.42	1.28	3.155	32.300		
17	08/10/00	MFG4-3 #1 Cal	MFG	ALOX/Z	1.3135	63.98	2	62.465	-2.37	1.02	1.752	16.690	5.52	S
		MFG4-3 #2 Cal	MFG	ALOX/Z	1.3135	63.98	2	62.664	-2.06	1.18	1.752	16.750		S
		MFG4-3 #3 Cal	MFG	ALOX/Z	1.3135	63.98	2	62.764	-1.91	1.30	1.752	16.780		
		MFG4-3 #4 Cal	MFG	ALOX/Z	1.3135	63.98	2	62.565	-2.22	1.13	1.752	16.720		
15	08/08/00	DQA-7 #1 Perf. (VISAR)		Al 6061-T651	1.386	180.0							15.72	
		DQA-7 #2 Perf. (VISAR)		Al 6061-T651	1.386	180.0								
16	08/09/00	DQA-8 #1 Perf. (& VISAR)	DQA	Al 6061-T651	1.190	151.3	1	150.965	-0.19	0.7	3.54	36.520	3.17	
		DQA-8 #2 Perf. (& VISAR)	DQA	Al 6061-T651	1.190	151.3	1	152.406	0.76	1.17	3.54	36.870		

Notes

* Compensated for Wheatstone bridge nonlinearity
PC - Previously calibrated
ALOX/Z is new batch
S - Spare power supply
1 - DQA 2000
2 - MAC97
3 - MAC00

^ Deviation of gage reading from actual level
@ Anomalous, verified by add on test MFG4-3
$ Anomalous, gage shorted

Table B.3 Comparison of PMMA Gas Gun Tests Done in 1995, 1997, 1998, and 2000

Test ID & 2000* Level (kbar)	Target Material	Gage	Gage*** Readings (kbar)	Dev.# (%)	1998* Level (kbar)	Target Material	Gage	Gage*** Readings (kbar)	Dev.# (%)	1997* Level (kbar)	Target Material	Gage	Gage*** Readings (kbar)	Dev.# (%)	1995* Level (kbar)	Target Material	Gage	Gage** Readings (kbar)	Dev.# (%)
32.04	PMMA	1	31.57	-1.5	33.19	PMMA	1	32.32	-2.6	32.99	PMMA	1	33.36	1.1	30.4	PMMA	1	31.17	2.5
MFG4-SU1		2	31.79	-0.8								2	33.30	0.9			2	31.30	3.0
33.37	PMMA	1	32.49	-2.6	32.59	PMMA	1	31.21	-4.2	32.96	PMMA	1	32.62	-1.0	30.4	PMMA	1	29.56	-2.8
MFG4-SU2		2	32.42	-2.8			2	31.31	-3.9			2	32.69	-0.82			2	29.16	-4.1
																	3	29.84	-1.8
																	4	29.71	-2.3
33.18	PMMA	1	31.54	-5.0															
DQA-1		2	31.39	-5.4															
38.27	PMMA	1	36.50	-4.6															
DQA-2		2	36.94	-3.5															

* Pressure level determined by Gas Gun generated particle velocity and PMMA Hugoniot Data.

** Manganin Gage output pressure determined using the 1995 (NDB) calibration curve.

*** Manganin Gage output pressure determined using (MAC97) calibration curve.

Deviation of gage reading from actual level

Test results from calibration test series June 28 00.xls

Table B.4 Comparison of ALOX Gas Gun Tests done in 1995, 1997, 1998, and 2000

Test ID & 2000* Level (kbar)	Target Material	Gage	Gage*** Readings (kbar)	Dev.# (%)	1998* Level (kbar)	Target Material	Gage	Gage*** Readings (kbar)	Dev.# (%)	1997* Level (kbar)	Target Material	Gage	Gage*** Readings (kbar)	Dev.# (%)	1995* Level (kbar)	Target Material	Gage	Gage** Readings (kbar)	Dev.# (%)
33.91	New	1	33.45	-1.4	33.45	ALOX	1	34.06	1.8	33.06	ALOX	1	34.53	4.4	33.76	ALOX	1	34.09	0.98
MFG4-1	ALOX/Z	2	33.16	-2.2		/459	2	33.79	1.0		/Z	2	33.75	2.1		/Z	2	33.7	-0.2
		3 PC	32.99	-2.7													3	33.22	-1.6
		4 PC	35.05	3.4													4	33.53	-0.68
32.52	New	1	32.78	0.8	33.11	ALOX	1	33.82	2.1	32.91	ALOX	1	34.21	4.0	33.9	ALOX	1	34.1	0.59
MFG4-2	ALOX/Z	2	32.71	0.6		/459	2	33.48	1.1		/Z	2	34.43	4.6		/Z	2	34.18	0.83
		3 PC	31.32	-3.7													3	33.3	-1.8
		4 PC	32.85	1.0													4	N/A	N/A
62.05	New	1	57.74	-6.9@	59.87	ALOX	1	61.13	2.1	59.46	ALOX	1	61.2	2.9	61.28	ALOX	1	63.78	4.1
MFG4-4	ALOX/Z	2	62.40	0.6		/459	2	61.63	2.9		/Z	2	61.18	2.9		/Z	2	61.78	0.82
		3 PC	64.06	3.2													3	60.70	-0.95
		4 PC	63.30	2.0													4	61.55	0.44
63.20	New	1	62.70	-0.8	60.02	ALOX	1	60.14	0.2	59.46	ALOX	1	60.46	1.7	61.66	ALOX	1	60.64	-1.7
MFG4-5	ALOX/Z	2	62.66	-0.8		/459					/Z	2	59.96	0.84		/Z	2	61.06	-0.97
		3 PC	63.30	0.2													3	60.01	-2.7
		4 PC	61.37	-2.9													4	N/A	N/A
63.98	New	1	62.47	-2.4															
MFG4-3	ALOX/Z	2	62.66	-2.1															
		3	62.76	-1.9															
		4	62.57	-2.2															

* Pressure level determined by Gas Gun generated particle velocity and ALOX Hugoniot Data.
** Manganin Gage output pressure determined using the 1995 (NDB) calibration curve.
*** Manganin Gage output pressure determined using (MAC97) calibration curve.
PC - Previously calibrated gage obtained from bonded stores
\# Deviation of gage reading from actual level
@ Anomaly, see Section 2.3.2

Test results from calibration test series June 28 00.xls

Table B.5 Previous Calibration Test Series Data

Test Date	Test	Buffer Material	Projectile Impact Velocity (mm/us)	Pressure from Hugoniot (kbar)	Fit	Gage Pressure (kbar)	Dev. (%)	Cable Res. (ohms)	Initial Peak Voltage (V)	Dror* (%)
Mar-95	PT-1 #1	PMMA	1.4084	30.4	1	31.171	2.54	0.37	0.8	7.191
Mar-95	PT-1 #2	PMMA	1.4084	30.4	1	31.299	2.96	0.37	0.804	7.228
Mar-95	PT-2 #1	PMMA	1.3961	30.4	1	29.556	-2.78	2.05	0.732	6.732
Mar-95	PT-2 #2	PMMA	1.3961	30.4	1	29.160	-4.08	0.93	0.732	6.621
Mar-95	PT-2 #3	PMMA	1.3961	30.4	1	29.837	-1.85	0.98	0.752	6.811
Mar-95	PT-2 #4	PMMA	1.3961	30.4	1	29.711	-2.27	0.63	0.752	6.776
Mar-95	PT-3 #2	PMMA	1.3979	30.4	1	30.737	1.11	0.94	0.78	7.067
Mar-95	PT-3 #3	PMMA	1.3979	30.4	1	31.226	2.72	0.86	0.796	7.207
Apr-95	AT05A #1	ALOX/Z	0.1574	5.54	1	5.359	-3.26	0.93	0.114	1.011
Apr-95	AT05A #2	ALOX/Z	0.1574	5.54	1	5.805	4.78	1.39	0.123	1.099
Apr-95	AT05A #3	ALOX/Z	0.1574	5.54	1	5.738	3.57	0.85	0.1225	1.086
Apr-95	AT05A #4	ALOX/Z	0.1574	5.54	1	5.583	0.77	0.89	0.119	1.055
Apr-95	AT05B #1	ALOX/Z	0.1581	5.57	1	5.450	-2.15	0.64	0.1165	1.029
Apr-95	AT05B #2	ALOX/Z	0.1581	5.57	1	5.448	-2.19	0.61	0.1165	1.028
Apr-95	AT05B #3	ALOX/Z	0.1581	5.57	1	5.573	0.05	0.76	0.119	1.053
Apr-95	AT05B #4	ALOX/Z	0.1581	5.57	1	5.461	-1.96	0.78	0.1165	1.031
Apr-95	AT33A #1	ALOX/Z	0.7916	33.76	1	33.222	-1.59	1.05	0.856	7.787
Apr-95	AT33A #2	ALOX/Z	0.7916	33.76	1	33.705	-0.16	0.99	0.872	7.930
Apr-95	AT33A #3	ALOX/Z	0.7916	33.76	1	34.088	0.97	0.69	0.888	8.043
Apr-95	AT33A #4	ALOX/Z	0.7916	33.76	1	33.534	-0.67	0.88	0.868	7.880
Apr-95	AT33B #1	ALOX/Z	0.7942	33.9	1	33.305	-1.76	0.94	0.86	7.812
Apr-95	AT33B #3	ALOX/Z	0.7942	33.9	1	34.177	0.82	0.91	0.888	8.070
Apr-95	AT33B #4	ALOX/Z	0.7942	33.9	1	34.096	0.58	0.71	0.888	8.046
Apr-95	AT61A #1	ALOX/Z	1.27	61.28	1	60.702	-0.94	0.89	1.728	16.135
Apr-95	AT61A #2	ALOX/Z	1.27	61.28	1	63.782	4.08	0.75	1.816	16.970
Apr-95	AT61A #3	ALOX/Z	1.27	61.28	1	61.779	0.81	0.81	1.76	16.431
Apr-95	AT61A #4	ALOX/Z	1.27	61.28	1	61.554	0.45	0.88	1.752	16.370
Apr-95	AT61B #1	ALOX/Z	1.276	61.66	1	60.640	-1.65	0.82	1.728	16.118
Apr-95	AT61B #3	ALOX/Z	1.276	61.66	1	60.013	-2.67	0.75	1.712	15.943
Apr-95	AT61B #4	ALOX/Z	1.276	61.66	1	61.059	-0.97	0.65	1.744	16.234
Apr-95	AT12 #2	ALOX/Z	0.32	11.88	1	11.622	-2.17	0.86	0.258	2.296
Apr-95	AT12 #3	ALOX/Z	0.32	11.88	1	12.576	5.86	0.38	0.283	2.503

Ext cal of manganin gage July 17 00.xls

Table B.5 Previous Calibration Test Series Data

Test Date	Test	Buffer Material	Projectile Impact Velocity (mm/us)	Pressure from Hugoniot (kbar)	Fit	Gage Pressure (kbar)	Dev. (%)	Cable Res. (ohms)	Initial Peak Voltage (V)	Dror* (%)
Apr-95	AT12 #4	ALOX/Z	0.32	11.88	1	11.494	-3.25	0.84	0.255	2.269
Apr-95	AT19 #1	ALOX/Z	0.4971	19.49	1	19.123	-1.88	0.76	0.448	4.005
Apr-95	AT19 #2	ALOX/Z	0.4971	19.49	1	19.007	-2.48	0.9	0.444	3.977
Apr-95	AT19 #3	ALOX/Z	0.4971	19.49	1	20.476	5.06	0.81	0.484	4.336
Apr-95	AT19 #4	ALOX/Z	0.4971	19.49	1	20.448	4.91	0.7	0.484	4.328
Apr-95	AT26 #1	ALOX/Z	0.6945	28.83	1	28.128	-2.44	0.83	0.702	6.334
Apr-95	AT26 #2	ALOX/Z	0.6945	28.83	1	27.497	-4.62	0.75	0.684	6.161
Apr-95	AT26 #3	ALOX/Z	0.6945	28.83	1	30.328	5.20	0.89	0.768	6.950
Apr-95	AT26 #4	ALOX/Z	0.6945	28.83	1	28.073	-2.63	0.67	0.702	6.319
Apr-95	AT47 #1	ALOX/Z	1.044	47.61	1	47.616	0.01	0.77	1.33	12.235
Apr-95	AT47 #2	ALOX/Z	1.044	47.61	1	47.398	-0.45	0.92	1.32	12.167
Apr-95	AT47 #3	ALOX/Z	1.044	47.61	1	47.746	0.29	0.73	1.335	12.276
Apr-95	AT47 #4	ALOX/Z	1.044	47.61	1	47.252	-0.75	0.67	1.32	12.121
Apr-95	AT54 #1	ALOX/Z	1.176	55.45	1	54.868	-1.05	0.76	1.56	14.457
Apr-95	AT54 #2	ALOX/Z	1.176	55.45	1	56.033	1.05	0.73	1.596	14.802
Apr-95	AT54 #3	ALOX/Z	1.176	55.45	1	56.611	2.09	0.96	1.608	14.971
Apr-95	AT54 #4	ALOX/Z	1.176	55.45	1	56.479	1.86	0.79	1.608	14.933
Apr-95	PDL33A #1	ALOX/Z HTC	0.788	33.58	1	34.589	3.00	0.69	0.904	8.192
Apr-95	PDL33A #2	ALOX/Z HTC	0.788	33.58	1	33.253	-0.97	0.81	0.86	7.797
Apr-95	PDL33A #3	ALOX/Z HTC	0.788	33.58	1	34.067	1.45	0.95	0.884	8.037
Apr-95	PDL33A #4	ALOX/Z HTC	0.788	33.58	1	33.202	-1.13	1	0.856	7.782
Apr-95	PDL40A #1	ALOX/Z HTC	0.94	41.73	1	41.080	-1.56	0.93	1.112	10.182
Apr-95	PDL40A #2	ALOX/Z HTC	0.94	41.73	1	40.769	-2.30	1.04	1.1	10.085
Apr-95	PDL40A #3	ALOX/Z HTC	0.94	41.73	1	41.147	-1.40	0.82	1.116	10.203
Apr-95	PDL40A #4	ALOX/Z HTC	0.94	41.73	1	40.483	-2.99	0.7	1.096	9.996

Ext cal of manganin gage July 17 00.xls

Table B.5 Previous Calibration Test Series Data

Test Date	Test	Buffer Material	Projectile Impact Velocity (mm/us)	Pressure from Hugoniot (kbar)	Fit	Gage Pressure (kbar)	Dev. (%)	Cable Res. (ohms)	Initial Peak Voltage (V)	Dror* (%)
Aug-97	SU033A #1	PMMA	1.492	32.99	2	32.986	-0.01	1.09	0.86	7.829
Aug-97	SU033A #2	PMMA	1.492	32.99	2	32.916	-0.22	0.92	0.86	7.810
Aug-97	SU033B #1	PMMA	1.491	32.96	2	32.217	-2.25	1.48	0.832	7.612
Aug-97	SU033B #2	PMMA	1.491	32.96	2	32.289	-2.03	1.00	0.84	7.632
Aug-97	RCT033A #1	ALOX/Z	0.778	33.06	2	34.531	4.45	1.02	0.908	8.271
Aug-97	RCT033A #2	ALOX/Z	0.778	33.06	2	33.750	2.09	1.03	0.884	8.047
Aug-97	RCT033B #1	ALOX/Z	0.775	32.91	2	34.210	3.95	0.88	0.9	8.178
Aug-97	RCT033B #2	ALOX/Z	0.775	32.91	2	34.430	4.62	1.09	0.904	8.242
Aug-97	RCT061A #1	ALOX/Z	1.241	59.46	2	61.198	2.92	0.95	1.744	16.308
Aug-97	RCT061A #2	ALOX/Z	1.241	59.46	2	61.182	2.90	0.93	1.744	16.303
Aug-97	RCT061B #1	ALOX/Z	1.241	59.46	2	60.201	1.25	1.01	1.712	16.006
Aug-97	RCT061B #2	ALOX/Z	1.241	59.46	2	59.964	0.85	1.04	1.704	15.935
Aug-97	RCT005A #1	ALOX/Z	0.1419	4.97	2	5.039	1.48	1.00	0.112	0.994
Aug-97	RCT005A #2	ALOX/Z	0.1419	4.97	2	5.049	1.68	1.14	0.112	0.996
Aug-97	RCT005B #1	ALOX/Z	0.136	4.75	2	4.987	4.99	0.88	0.111	0.984
Aug-97	RCT005B #2	ALOX/Z	0.136	4.75	2	4.782	0.68	1.08	0.106	0.942
Aug-97	RCT080A #1	ALOX/Z	1.564	80.77	2	79.810	-1.19	0.91	2.29	21.794
Aug-97	RCT080A #2	ALOX/Z	1.564	80.77	2	79.477	-1.60	0.93	2.28	21.699
Aug-97	RCT100A #1	ALOX/Z	1.019	97.37	2	99.538	2.22	0.97	2.83	27.459
Aug-97	RCT100A #2	ALOX/Z	1.019	97.37	2	97.926	0.57	1.12	2.78	26.990
Aug-97	RCT100B #2	ALOX/Z	1.030	98.78	2	97.941	-0.85	1.13	2.78	26.994
Aug-97	RCT080B #1	ALOX/Z	1.560	80.49	2	79.604	-1.11	1.04	2.28	21.735
Aug-97	RCT080B #2	ALOX/Z	1.560	80.49	2	81.320	1.03	1.04	2.328	22.229
Aug-97	RCT001B #1	ALOX/Z	0.031	1.04	2	1.097	4.98	1.60	0.0236	0.211
Aug-97	RCT001B #2	ALOX/Z	0.031	1.04	2	1.341	28.41	0.92	0.0292	0.258
Aug-97	RCT001C #1	ALOX/Z	0.0297	1.00	2	0.702	-29.87	0.98	0.0152	0.134
Aug-97	RCT001C #2	ALOX/Z	0.0297	1.00	2	0.857	-14.33	0.93	0.0186	0.164

Table B.5 Previous Calibration Test Series Data

Test Date	Test	Buffer Material	Projectile Impact Velocity (mm/us)	Pressure from Hugoniot (kbar)	Fit	Gage Pressure (kbar)	Dev. (%)	Cable Res. (ohms)	Initial Peak Voltage (V)	Dror* (%)
Jul-98	RPP033A #1	PMMA	1.499	33.19	2	32.319	-2.62	1.65	0.833	7.641
Jul-98	RPP033B #1	PMMA	1.478	32.59	2	31.207	-4.24	1.46	0.802	7.328
Jul-98	RPP033B #2	PMMA	1.478	32.59	2	31.310	-3.93	0.87	0.812	7.357
Jul-98	R4A033A #1	ALOX/459	0.7856	33.45	2	34.062	1.83	1.07	0.893	8.136
Jul-98	R4A033A #2	ALOX/459	0.7856	33.45	2	33.791	1.02	2.39	0.868	8.059
Aug-98	R4A061A #1	ALOX/459	1.2475	59.87	2	61.133	2.11	0.91	1.743	16.288
Aug-98	R4A061A #2	ALOX/459	1.2475	59.87	2	61.625	2.93	1.23	1.75	16.437
Aug-98	R4A033B #1	ALOX/459	0.779	33.11	2	33.815	2.13	1.34	0.882	8.065
Aug-98	R4A033B #2	ALOX/459	0.779	33.11	2	33.480	1.12	1.09	0.875	7.970
Aug-98	R4A005B #1	ALOX/459	0.114	3.96	2	3.675	-7.20	1.01	0.081	0.719
Aug-98	R4A005B #2	ALOX/459	0.114	3.96	2	3.760	-5.06	1.10	0.0828	0.736
Aug-98	R4A061B #2	ALOX/459	1.25	60.02	2	60.142	0.20	1.10	1.708	15.989
Aug-98	RZA061A #1	ALOX/Z	1.265	60.96	2	60.387	-0.94	1.12	1.715	16.063
Aug-98	RZA061A #1	ALOX/Z	1.265	60.96	2	60.298	-1.09	1.01	1.715	16.036

* Calculated directly from voltage reading off the waveform digitizer

1 - 1995 NDB

2 - MAC97 Ext

HTC - high temperature cure

459 - hardener (gave same results as Z)

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Appendix C. Compensation for Wheatstone Bridge Nonlinearity

- Compensation for Wheatstone bridge nonlinearity

Compensation for Wheatstone Bridge Impedance changes.

Figure C.1 is a simplified schematic drawing of the wheatstone bridge circuitry used to conduct the tests described in this report. With 50 ohms (Rg) attached to the bridge input, the output impedance is 75 ohms. If fast rise time signals are to be recorded, the output of this bridge should be terminated with it's characteristic impedance i.e. 75 ohms. This termination results in a signal division that reduces the output by a factor of 2. When there are large resistance changes by the transducer, the output impedance of the bridge may change enough to significantly effect the magnitude of the signal monitored by the recorder, i.e. the division ration will be something other than a factor of 2. This is shown in the equivalent circuit shown in Figure C.2.

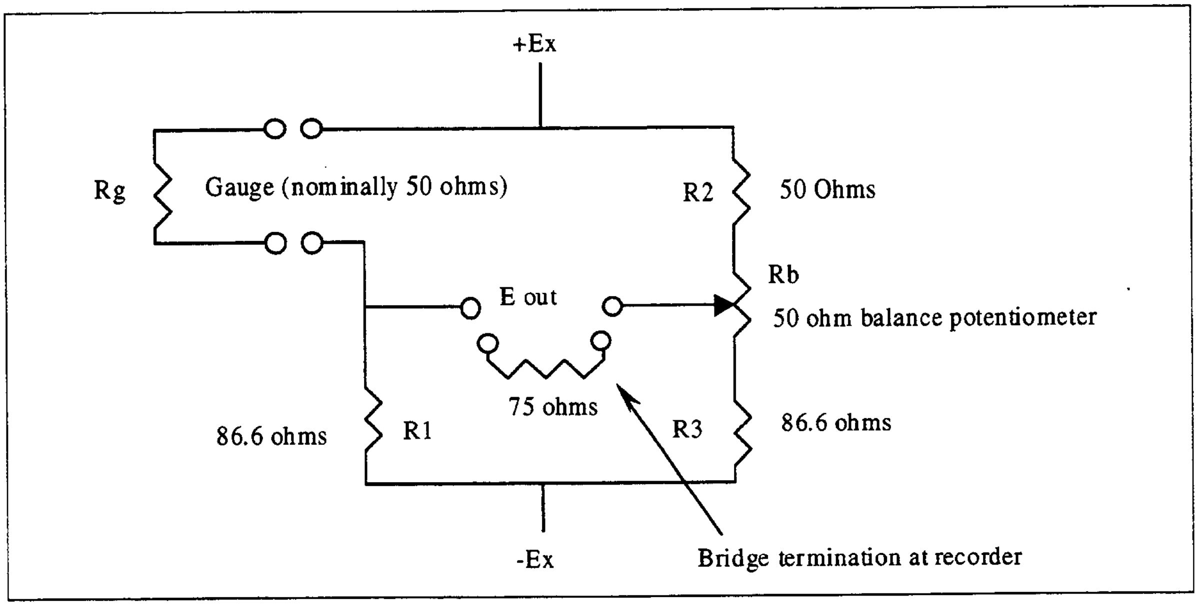

Figure C.1 Wheatstone bridge with 75 ohm output impedance.

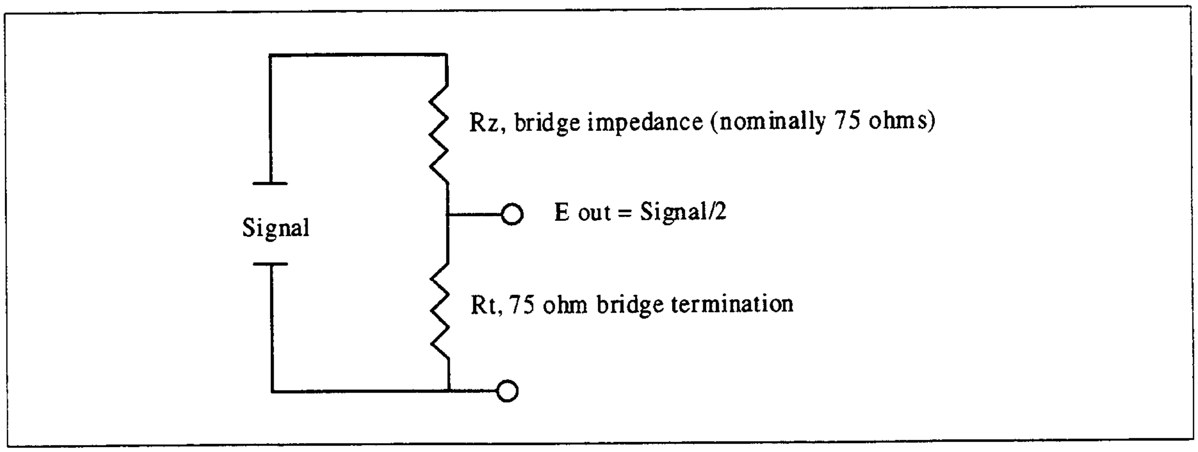

Figure C.2 Equivalent bridge output circuitry.

"E out" may be calculated using the following formula.

$$E\ out = Signal*Rt/(Rz+Rt)$$

This illustrates that "E out" will be ½ of signal as long as the bridge impedance and the bridge termination is equal, however when the bridge impedance changes (increases in this case) the multiplier to determine the true value of signal is no longer 2.

In order to compensate for the change in bridge impedance, the change in resistance of the transducer at any point in time must be known (ΔR). This is very difficult to calculate directly since the output reading and subsequent calculation of ΔR is based upon a division ratio that is unknown and can't be calculated without knowing ΔR. The solution involves a loop that increments ΔR and also calculates the division ratio and resulting output, until the output matches the as read value. This ΔR/R value then is used to determine the actual pressure seen by the gauge using the appropriate pressure vs. ΔR/R relationship.

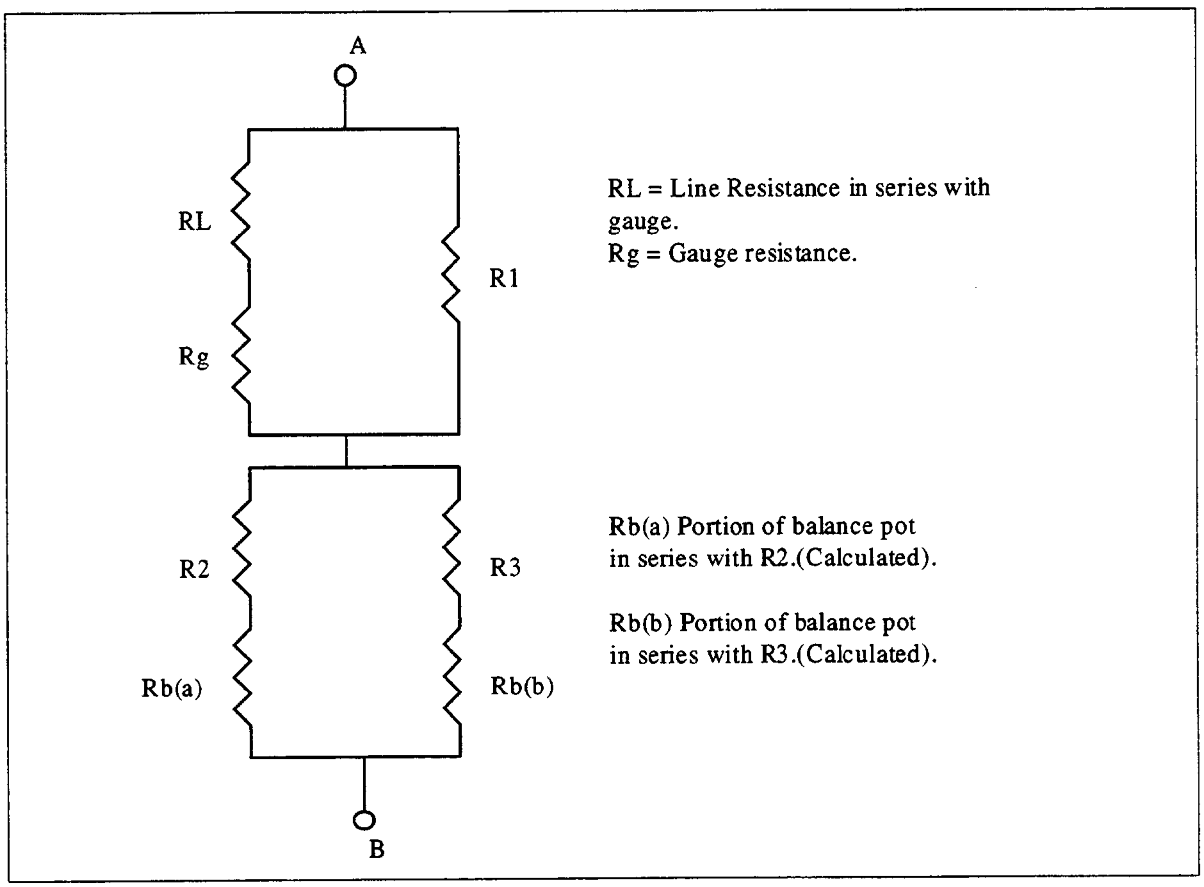

Figure C.3 Equivalent bridge circuit used to determine the output impedance.

In order to make the output impedance of the bridge circuit more readily apparent, the equivalent circuit is redrawn as shown in Figure C.3 with points A and B representing the output terminals of the bridge. The position of the balance pot for each test is calculated based upon the combination of line resistance and gage resistance. The resulting balance pot resistances are shown in series with R2 and R3 respectively.

The computer code that is used to calculate the effect of the impedance change, as described above, is shown below.

```
Ex = 100 volts. ! Bridge excitation voltage.
Rg = 48
E = Output voltage of the wheatstone bridge "as read".
RL= Line resistance in series with the gauge.
Rem Compute the setting of the balance pot in order to balance the bridge.
R11 = (RL+Rg)/(Rg+RL+86.6)*186.6 ! R2 + calculated portion of balance pot.
R12 = 186.6-R11 !  R3 + calculated portion of the balance pot.
Rem Determine actual ΔR/R to achieve indicated voltage out.  Correction for
bridge impedance is included.
For M = Rg +.01 to 85 step .01
Voc = Ex*(86.6/(86.6+Rg+RL))-Ex*(86.6/(86.6+RL+M))
Rb = ((R12*R11)/(R12+R11))+((86.6*(M+RL))/(86.6+M+RL))
Vind = Voc *75/(75+Rb)
If Vind > E then 20
Next M
Print "Rg+Delta R Exceeds 85 ohms and is beyond the verified calibration
range."
Stop
20 Dror = ((M-48)/48)*100
Press = 4.47907+3.38811*dror+.0506272*Dror^2-
.00144808*Dror^3+.0000144828*Dror^4.
```

This program may be used to calculate a single value of corrected pressure from this bridge output "E" or it may be added to the data reduction program to correct the data points from a test sequence. The corrected $\Delta R/R$ then may be used with the DQA 2000 program (see Figure 14) to arrive at the actual measured pressure using the appropriate $\Delta R/R$ vs. pressure curve fit.

Distribution

1	MS-0521	Steve Montgomery	2561
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1	MS-1453	Toby Garcia	2553
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